AIRCO Welding Products

* TRAINING CENTER *

KING OF PRUSSIA, PA.

WELDING FILLER METALS

STUDENTS NAME____________________________

DATE__________________

SECTION A

SHIELDED METAL-ARC WELDING

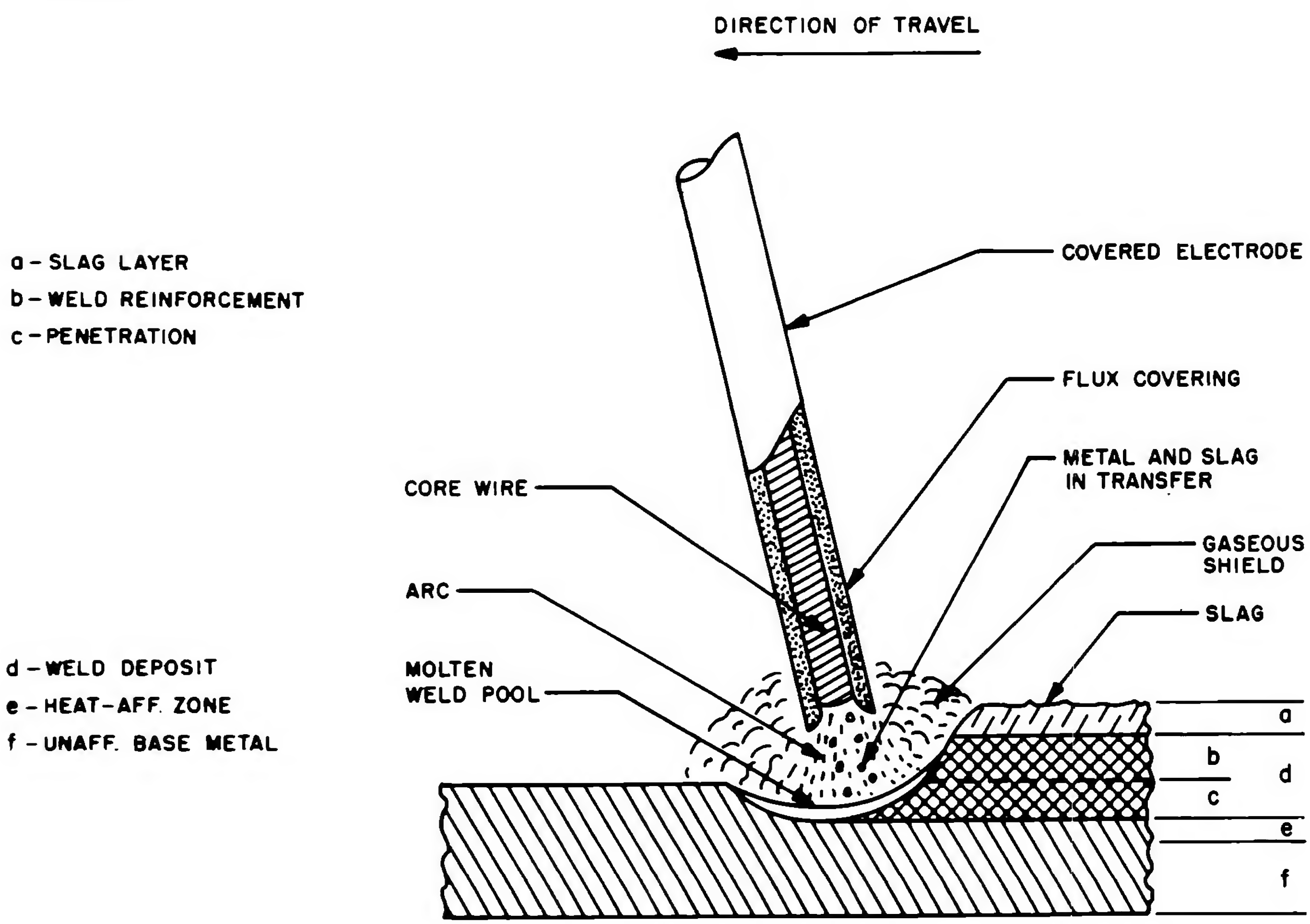
BASIC PROCESSES DESCRIPTION

Shielded Metal-Arc or "Stick Electrode" Welding is by far the most widely used of the various electrode arc welding processes. As the name implies, rods of core wire are coated by a layer of material whose principle function is to shield the molten from the harmful effects of surrounding air. Coverings consist of layers of substantial thickness applied extrusion and represent a carefully formulated mixture of many materials. These include fluxing, slag-forming, gas-forming ingredients, emissive agents, etc.

Much shielded metal-arc welding is carried out with the more heavily flux-covered electrode as illustrated in the accompanying sketch. The electrode covering serves to shield the heated tip of the electrode, and upon melting will stabilize the arc by adding readily ionized substances to the plasma. The gases generated by the covering materials offer a good amount of protection from oxidation and nitrogen pick-up to the metal during melting and transfer across the arc, while the slag-forming ingredients protect the weld bead as it solidifies and cools to room temperature. Powdered metals often are included in the covering for purposes of alloying, deoxidation and improving the handling characteristics of

the electrode. The ingredients in an electrode covering can have a powerful influence upon the characteristics of the welding arc. The distribution of heat as with any arc welding process can be concentrated at the electrode or the base metal and is dependent upon electrode polarity. However, by ingredients, the electrode can be made to deeply penetrate the base metal, or to produce light penetration but with good ability to bridge open gaps.

The recent development of composite type electrodes i.e., mild steel core wire with alloying ingredient placed in the coating, have greatly reduced manufacturing costs and have provided industry with an improved quality electrode and increased metal deposition rates.

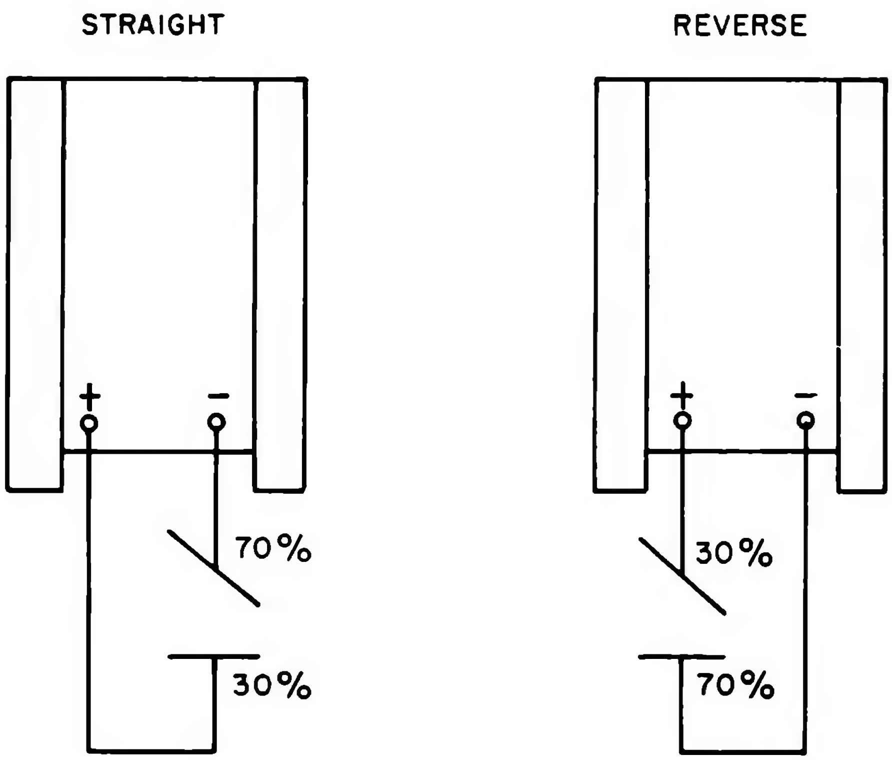


Reference to Figure 2, makes a comparison between direct current straight polarity and direct current reverse polarity. Notice that there is a decided difference between the two arc polarities with a greater portion of the arc heat being concentrated at the cathode or negative terminal. This simply means that if we were to attach our electrode lead to the negative terminal of a D.C. power source, our electrode deposition rate will be far greater than our penetration by a factor of approximately 7.3 and vice-versa. This phenomenon holds true for all consumable electrode welding processes; that is, stick electrodes, MIG, and submerged arc. It does not apply to the non-consumable electrode welding process called gas tungsten-arc or TIG because of the thermionic properties unique to tungsten.

In order to help you remember which terminal, the electrode is attached to in straight and reverse polarity, you will find at the bottom of Figure 2 a little rule of thumb to help jog your memory.

POLARITY OF THE ARC AND HEAT CONCENTRATION

WITH CONSUMABLE ELECTRODE WELDING



70% ARC HEAT IS CONCENTRATED AT THE CATHODE (-)

30% ARC HEAT AT THE ANODE (+)

Figure 2

THE PROCESSES AND ARC CHARACTERISTICS DESIRABLE WILL DETERMINE THE ARC POLARITY

THIS WILL HELP YOU REMEMBER ELECTRODE TERMINAL

The rule of thumb to remember in connecting the electrode to a power supply is to recall the Congress of the United States. We have a SENator and a REPresentative as:

Straight Electrode Negative * * * SEN

Reverse Electrode Positive * * * REP

HISTORY OF ARC WELDING ELECTRODES

In Germany in 1892, the first patent was granted for an arc welding process employing a consumable electrode. This bare wire electrode was employed with DC current straight polarity. It was very difficult to hold a stable arc with a bare electrode and the deposited metal was very poor in physical and chemical properties.

In Sweden in 1907, a patent was granted for a shielded arc electrode. This electrode was made by dipping the wire in a lime solution. The thin lime coating acted only as an arc stabilizing agent as there was insufficient material to provide either slag or fluxing.

In England in 1912, the first really successful coated electrode was made and in that year a patent was granted in the United States for this electrode. This electrode was made of long fibre blue asbestos wound around a steel core wire. The coating was cemented in place with liquid sodium silicate which was a standard fireproofing material at that time. Virtually nothing was known of electrode coating chemistry at this time, but fortunately, a material with many desirable properties was thus discovered. (Today, most electrodes use sodium silicate in considerable quantities). The coating of this electrode was very heavy and though quite an improvement, it would be considered unsatisfactory compared with modern day electrodes.

During World War I, England imported large quantities of these electrodes. Later war contracts were sucontracted in the United States. These contracts specified coated electrodes. One of these subcontractors, a large steel fabricator, experimented with many different materials. A coating was made of spiral wood paper cemented in place with liquid sodium silicate. With this electrode welds could be made in all positions that would produce good ductility and tensile strengths.

Paper is a good source of cellulose, and sodium silicate is a good fluxing agent and slag producing agent, as well as a cementing agent; thus; a new electrode was born that was destined to have far reaching effects on steel fabrication.

These two early electrodes, the acid slag, mineral type that originated in Europe, and the basic slag, cellulose type that originated in the United States, were the parents of all of our modern day electrodes.

The first low hydrogen electrode was made in 1939 for welding chromium-molybdenum castings. In 1941, the first low hydrogen electrode was made in large quantities for welding of cast manganese-molybdenum armor. This armor had been welded with stainless steel electrodes which were expensive and required large quantities of scarce materials. The first successful low hydrogen electrode was made with a coating very similar to the coating of the stainless steel electrodes which it replaced. It was at this time that people in the metallurgical field found the part HYDROGEN played in the welding of high tensile steels. Underbead cracking was virtually eliminated by the elimination of HYDROGEN and HYDROGEN BEARING MATERIALS from the electrode coatings.

The first successful electrodes for alternating current operation were manufactured in 1942. Prior to this time, AC electrodes were very unsatisfactory. Two new classes of electrodes were made: The Class E-6011 and the Class E-6013.

The first iron powder electrodes were made in Holland. They were introduced to the United States in 1946, but were unacceptable due to the conductivity to the coating. In 1953, a non-conductive iron powder coating was created in the United States and introduced with immediate success. This new electrode was AWS Class E-7024.

The welding industry made great strides forward during both the First and Second World Wars. The urgency of the armament program and the resulting scarcity of materials brought about new developments with far reaching effects.

ELECTRODE MANUFACTURING PROCEDURE

RAW MATERIALS

Electrode manufacturing is one of the most complicated trades that industry has to offer. To begin with, the raw material requirements are more complex than most people can imagine. There are over one hundred different raw materials that go into the production of welding electrodes. These materials consist of many minerals, ores, chemicals, and metallics that are very carefully controlled as to particle size, chemistry, and physical properties. These materials are bought to very strict specifications and expensive equipment is employed to insure that the specs are consistently met. Some of the equipment that is used for quality control are: X-ray defraction, Spectrometer, Chemical laboratory equipment and Metallurgical inspection equipment.

Most all of the raw materials are packaged in small lot containers so that no grinding takes place in shipment. The particle size of most raw materials is very important to the final operation characteristics of the finished electrode.

Chemical analysis is made on every lot of materials that is received to insure that our specs are met. Such things as sulfur and phosphorus are poison to the electrode manufacturer.

BATCHING

Electrodes are made in batch lots so that maximum control can be exercised in their mixing. All batches are mixed by referring to code charts. These codes are set up to protect the formulations from getting into competitive hands and also to insure that the correct material gets into the batch. The dry materials in the batch are mixed first and then the wet constituents are added after a pre-determined time. A heavy "MUD" is formed on wet mixing and the MUD is placed in a press to form a slug or cylinder. This cylinder is taken to the extrusion press for a production run. A usual production run amounts to about 40,000 pounds per run.

EXTRUDING

The extrusion press is a machine that takes the MUD and forms it around the core wire at very high speed. Fourteen inch electrodes are extruded from this machine at speeds of up to 1200 per minute. Strange as it sounds, electrodes are so competitive that 40,000 pounds have to be run before any profit is made by the production facility.

DRYING

Electrodes leaving the extrusion press are sent upon moving belts into a drying oven. The oven is graduated in temperature so that the green electrodes are sent into a low temperature first and gradually raised in temperature until a pre-determined water content is reached. Electrodes are never completely dry and in fact many have controlled water contents as part of the design. E-6010 types would not operate properly if they were completely dry.

FINISHED PRODUCT

After the electrodes come out of the oven they are sampled and each lot has operation and control tests made to insure that the product is made to specifications. A typical analysis can be obtained at no cost to the user. However, if an actual analysis of a specific heat is required, it must be requested by the user. There is an extra charge for this service dependent upon which specification the heat is being certified to.

Table 7—Covering Moisture-Content Requirements

AWS Classification[a]	Maximum Moisture Content, per cent by Weight
E7015-X, E7016-X, E7018-X	0.6
E8015-X, E8016-X, E8018-X, E9015-X, E9016-X	0.4
E9018-X, E10015-X, E10016-X, E10018-X, E11015-X, E11016-X, E11018-X, E12015-X, E12016-X, E12018-X	0.2

[a] The letter suffix "-X" as used in this table stands for all the suffixes (A1, B2, C3, M, etc.)

ELECTRODE COATINGS

The AWS-ASTM specifications place no restriction on the manufacture as to the materials used in the coating. The position of usability and electrical characteristics only are specified. This gives the industry a free hand to develope new ideas. The coatings of competitive electrodes are, however, very similar.

Certain elements are added to the coatings of electrodes as weld metal dioxidizers. The most common weld metal dioxidizers are ferromanganese and ferrosilicon. However, aluminum, titanium and zirconium are used occasionally.

Easily ionized materials such as potassium silicate are added to the coatings of some electrodes for better stability when welding with AC current. Alternating current passes through a zero value 120 times each second or two times each cycle. Each time the current changes polarity (disregarding the phase lag) there will be at that instant no flow of current. To re-establish the arc across the arc gap would require a welding machine of tremendous open circuit voltages. This type of welding machine simply is not practical.

Cellulose, which is usually obtained from wood flour, is the most common gaseous shield employed in electrode coatings. Unfortunately, cellulose, being an organic material, when heated liberates a mixture of carbon dioxide, carbon monoxide, water vapor and hydrogen. For this reason, some electrode coatings substitute powdered limestone which is almost pure calcium carbonate ($CaCO_3$) and when heated creates an almost hydrogen-free gaseous shield. The calcium carbonate liberates 44% of its weight as a mixture of carbon monoxide and carbon dioxide gas.

The slag is employed to lock out the harmful effects of the atmosphere. It is composed of oxides of hard-to-reduce metals, such as calcium, silicon, manganese and aluminum. The slag also acts to retard the cooling rate. Slags should have a different coefficient of expansion for easy removal.

Fluxing agents such as calcium oxide (which is derived from lime after calcination in the arc), sodium oxide (which is derived from sodium carbonate), sodium silicate and fluorspar (CaF_2, a calcium flurine compound) are added to the coating. This flux acts as a cleaning agent dissolving the mill scale and rust, but even more important, it dissolves oxides which may be formed despite the gaseous shield protection around the arc.

The electrode coating also contains fiberous materials such as asbestos for binding, liquid sodium silicate or potassium silicate for a cementing agent, clay and talc for plasticizing and slippage in the extrusion process. All of these materials are very carefully compounded and mixed to exacting proportions to produce the desired electrode characteristics.

AWS-ASTM ELECTRODE CLASSIFICATION SYSTEM

In order to acquire knowledge of any subject, it is necessary first to learn the language. It is necessary that we not only learn about our products, we must learn about competitive products as well. This is most easily accomplished by becoming familiar with standard specifications. The AWS-ASTM (American Welding Society-American Society For Testing Materials), Electrode Classification System, as shown on Page 12 of this Training Manual, outlines the system by which electrodes are classified. The letters and numbers of the AWS Classification System will provide detailed information about the physical and chemical properties of the deposited metal, the position of usability, and the electrical characteristics of the electrode. These numbers also will reveal the principal materials used in the electrode coating.

The prefix "E" before the AWS number denotes electrode. The first two numbers of the Classification System denote the tensile strength in thousand pounds per square inch. It will be noted that an E-6010 electrode has a tensile strength of 60,000 pounds. Correspondingly and E-7010-Al electrode will have a tensile strength of 70,000 pounds.

The third number denotes the position of usability. An E-6010 electrode has a number "1" for the third number. This number "1" denotes that the electrode is usable in all positions, i.e., flat, vertical, horizontal and overhead. If this number were a "2", such as in the number for Class E-6020 electrodes, the electrode usability would be limited to the flat and horizontal positions. If this third number were a "3", such as E-6030 electrodes, the position of usability would be limited to the flat position only.

The fourth number in the AWS Classification System denotes the principal materials of the coating. This number does not reveal to us all of the materials used in the coating, but it does define the principal materials that give an electrode its own peculiar characteristics. It should be noted the number "O" is used in two instances. The "O" is used to denote both cellulose sodium and iron oxide. In this case, reference must be made to the third number in addition to the last number. For instance, an electrode of Class E-6010 has a cellulose-sodium coating, an electrode of Class E-6020 has an iron-Oxide coating.

AWS-ASTM ELECTRODE CLASSIFICATION SYSTEM

E-XXXX	-	Electrode
E-60XX	-	Minimum tensile strength in thousands P.S.I.
E-XX1X	-	Third number (1) denotes all positions
E-XX2X	-	Third number (2) denotes flat and horizontal positions only
E-XX3X	-	Third number (3) denotes flat position only

RELATION BETWEEN ELECTRODE COATING AND ELECTRICAL CHARACTERISTICS

		DCSP	DCRP	AC
E-XXX0	Cellulose Sodium	-	X	-
0	Iron Oxide	X	X	X
1	Cellulose Potassium	-	X	X
2	Titania Sodium	X	-	X
3	Titania Potassium	X	-	X
4	Iron Powder Titania	X	X	X
5	Low Hydrogen Sodium	-	X	-
6	Low Hydrogen Potassium	-	X	X
7	Iron Oxide Iron Powder	X	X	X
8	Low Hydrogen Iron Powder	-	X	X

The coating determines the electrical characteristics of an electrode. Therefore, the fourth number also denotes the electrical characteristics.

It may readily be seen that a pattern is formed whereby a total of 51 mild steel and low alloy electrodes may be grouped in a classification system that permits understanding of their individual characteristics without the necessity of remembering a great amount of detail.

The deposits obtained from competing electrodes will be very close to the AWS-ASTM specifications but might vary quite a lot in operating characteristics and metallurgical characteristics. Even when chemistry of the weld metal is the same, MICROSCOPIC examination will reveal many non-metallic inclusions in some classes of deposited metal, such as, Class E-6012. These inclusions greatly affect the physical properties of the metal.

CORE WIRE IN ELECTRODES

The core wire used to manufacture mild steel electrodes and even low alloy electrodes is in most cases the same. It is usually a RIMMED steel wire drawn from the ingot form to retain the pure iron covering on the outside surface. A typical analysis is as follows:

Carbon - - - - - - - - - -	0.15 Maximum
Sulfur - - - - - - - - - -	0.04 Maximum
Phosphorus - - - - - - - -	0.04 Maximum
Silicon - - - - - - - - -	0.25 Maximum
Manganese - - - - - - - -	0.30 to 0.60

Sometimes a higher carbon core is used in E-6020 type electrodes for specific reasons. The main reason is to give better spray type transfer characteristics to the arc.

Thus, a complete classification number of an electrode under this specification would be E6010, E7016, etc., for example.

AWS A 5.1-69 limits the addition of alloying elements for all the E70XX classifications. There are no chemical requirements for all other classifications. Maximum limits are placed on chromium (0.20% max.), manganese (1.25% max.), nickel (0.30% max.), vanadium (0.08% max.), and silicon (0.90% max.) with the sum of these elements, excluding silicon, not to exceed 1.50%.

Under the Low-Alloy Steel Arc-Welding Electrode Specification (A 5.5-69) the classification system is similar to that of the Mild Steel Specification with the first two or three digits indicating tensile strength in the stress relieved condition in 1000 psi from E70XX, E80XX, E90XX to E100XX. The next two digits have the same meaning as in the Mild Steel Specification. In addition, following a dash, the chemical composition of the deposited metal is indicated by adding a letter and a final digit. Thus, the letter-A indicates a carbon-molybdenum steel electrode; the letter-B-, a chromium-molybdenum steel electrode; the letter-C-, a nickel steel electrode; the letter-D-, a manganese-molybdenum steel electrode; and finally the letter-G- is used for all other low alloy electrodes with minimum values for molybdenum (0.20% min.), chromium (0.30% min), manganese (1.00% min.), silicon (0.80% min.), nickel (0.50% min.) and vanadium (0.10% min.) specified. To meet the alloy requirements of the G group, the deposit need have a minimum, as specified, of only one of the elements listed. The final digit indicates the exact composition under one of these broad chemical classification. Thus, a complete classification number of an electrode would be E7010-A1, E8016-B2, etc., for example.

In the most recent revision of this specification a new class has been added, -M-. This has been done to further the correlation between the military and this specification.

Note that the requirements for E8016-C3 and E8018-C3 are identical to those for the MIL-8018 classification in MIL-22200/1 (SHIPS) and E9018-M, E11018-M are identical to those for MIL-9018, MIL-10018, MIL-11018.

For stainless steel electrode specification, AWS A5.4-69, a somewhat different system is employed. Since the analysis of the stainless steel deposit is of paramount importance, and further, since the American Iron and Steel Institute has identified stainless steels by type numbers, these type numbers are used in the classification identification. Thus, a stainless steel electrode classification consists of a letter (E for electrode), a three digit number (the AISI type number, such as 308, 316 or 347), a dash, and a two digit number (either 15 or 16) which indicate usability (welding power, coating type, etc.).

Non-ferrous electrodes are covered by separate specifications. Specifications for Aluminum and Aluminum Alloy Electrodes, AWS A-5.3-69 employ a classification number such as E-Al 43. Here, the E stands for electrode, Al for aluminum and 43 for the alloy composition, which in this case is 5% silicon. Specifications for Copper and Copper Alloy Electrodes, AWS A5.6-69 employ a classification system which uses chemical symbols of the principal alloying ingredients, e.g., ECuAl-A2. Again the E represents electrode, Cu-Copper, Al-Aluminum and A2 covers the composition. ECuAl-A2 covers an aluminum bronze electrode of the composition of Airco 100. Other copper alloy electrodes are identified in terms of the appropriate classification.

ELECTRODE USABILITY

TYPE XX10 - An all position, high cellulose coating used on dcrp only. The combustibles in this coating generate gases to shield the molten puddle and also form a relatively thin slag.

TYPE XX11 - This is similar to the XX10 coating except that additional of potassium compounds stabilizes the arc and permits use with ac.

TYPE XX12 - This is an all position electrode used with dcsp and ac. The titania-type coating produces a slag that shields the molten weld. The arc characteristics and slag make this type useful for easy handling, good weld profile and ability to bridge "gaps" in joint fitup. This is widely used in fillet welds.

TYPE XX13 - This coating is very similar to Type XX12 except that additional arc ionizing ingredients are added to stabilize the arc for welding at low current on sheet metal with ac. In larger electrodes, a flatter shaped fillet occurs.

TYPE XX14 - This electrode has a coating similar to Types XX12 and XX13 electrodes and, in small diameters, can be used in all positions. Iron powder is added to the coating to increase deposition rates.

TYPE XX15 - This is a "low-hydrogen" coating with a high proportion of lime to provide a basic slag on the weld. This coating is effective for reducing H_2 absorption in the weld metal. It is used on dcrp only.

TYPE XX16 - This coating is also a low-hydrogen type similar to XX15, but added potassium stabilizes the arc and permits use on ac as well as dcrp.

TYPE XX18 - A low-hydrogen coating similar to XX16, except that iron powder is added to increase deposition rates and improve operating characteristics.

TYPE XX20 - This type coating has a very fluid slag, high in iron oxide that produces high quality welds in the flat or horizontal fillet position. It is usable on ac or dc and produces high quality, porosity-free welds in groove and fillet joints.

TYPE XX24 - This coating contains ingredients similar to the XX12, XX13 and XX14 types. However, a large amount (50.0%) of iron powder is added to increase deposition rate. This type may be used on ac or dc.

TYPE XX27 - This coating contains ingredients similar to those in the XX20 type. However, here too up to 50.0% iron powder is added to assure high deposition of fluid, high quality weld metal. These electrodes produce excellent radiographic quality, form a heavy slag and are used for groove or fillet welds in the flat position with ac or dc.

TYPE XX28 - These electrodes are similar to XX18 electrodes except that high amounts of iron powder limit this type to horizontal or flat welding.

Weld test specimen strength and ductility requirements

AWS-A5.5-69 Classification	Tensile Strength, min, psi	Yield Strength at 0.20 per cent offset, psi	Elongation in 2 in., min, per cent
E7010-X	70 000	57 000	22
E7011-X	70 000	57 000	22
E7015-X	70 000	57 000	25
E7016-X	70 000	57 000	25
E7018-X	70 000	57 000	25
E7020-X	70 000	57 000	25
E7027-X	70 000	57 000	25
E8010-X	80 000	67 000	19
E8011-X	80 000	67 000	19
E8013-X	80 000	67 000	16
E8015-X	80 000	67 000	19
E8016-X	80 000	67 000	19
E8018-X	80 000	67 000	19
E8016-C3	80 000	68 000 to 80 000	24
E8018-C3	80 000	68 000 to 80 000	24
E9010-X	90 000	77 000	17
E9011-X	90 000	77 000	17
E9013-X	90 000	77 000	14
E9015-X	90 000	77 000	17
E9016-X	90 000	77 000	17
E9018-X	90 000	77 000	17
E9018-M	90 000	78 000 to 90 000	24
E10010-X	100 000	87 000	16
E10011-X	100 000	87 000	16
E10013-X	100 000	87 000	13
E10015-X	100 000	87 000	16
E10016-X	100 000	87 000	16
E10018-X	100 000	87 000	16
E10018-M	100 000	88 000 to 100 000	20
E11015-X	110 000	97 000	15
E11016-X	110 000	97 000	15
E11018-X	110 000	97 000	15
E11018-M	110 000	98 000 to 110 000	20
E12015-X	120 000	107 000	14
E12016-X	120 000	107 000	14
E12018-X	120 000	107 000	14
E12018-M	120 000	108 000 to 120 000	18

TABLE 1

ELECTRODE CLASSIFICATION

AWS-ASTM Classification	Type of Covering	Cable of Producing Satisfactory Welds in Positions Shown[a]	Type of Current[b]
E60 Series--Minimum Tensile Strength of Deposited Metal in As-Welded Condition 60 000 PSI (or Higher--See Table 4)			
E6010	High cellulose Sodium	F,V,OH,H	dc, reverse polarity
E6011	High cellulose potassium	F,V,OH,H	ac or dc, reverse polarity
E6012	High titania sodium	F,V,OH,H	ac or dc, straight polarity
E6013	High titania potassium	F,V,OH,H	ac or dc, either polarity
E6020	High iron oxide	H-Fillets	ac or dc, straight polarity
		F	ac or dc, either polarity
E6027	Iron powder, iron oxide	H-Fillets	ac or dc, straight polarity
		F	ac or dc, either polarity
E70 Series--Minimum Tensile Strength of Deposited Metal in As-Welded Condition 70 000 PSI (or Higher--See Table 4)			
E7014	Iron powder, titania	F,V,OH,H	ac or dc, either polarity
E7015	Low hydrogen sodium	F,V,OH,H	dc, reverse polarity
E7016	Low hydrogen potassium	F,V.OH,H	ac or dc, reverse polarity
E7018	Iron powder, low hydrogen	F,V,OH,H	ac or dc, reverse polarity
E7024	Iron powder, titania	H-Fillets, F	ac or dc, either polarity
E7028	Iron powder, low hydrogen	H-Fillets, F	ac or dc, reverse polarity

[a]The abbreviations F, V, OH, H, and H-Fillets indicate welding positions (Figures 1 and 2) as follows:

F = Flat   H = Horizontal   H-Fillets = Horizontal Fillets

V = Vertical } For electrodes 3/16 in. and under, except 5/32 in. and under for
OH = Overhead } classifications E7014, E7015, E7016 and E7018

Reverse polarity means electrode is positive; straight polarity means electrode is negative.

TABLE 3

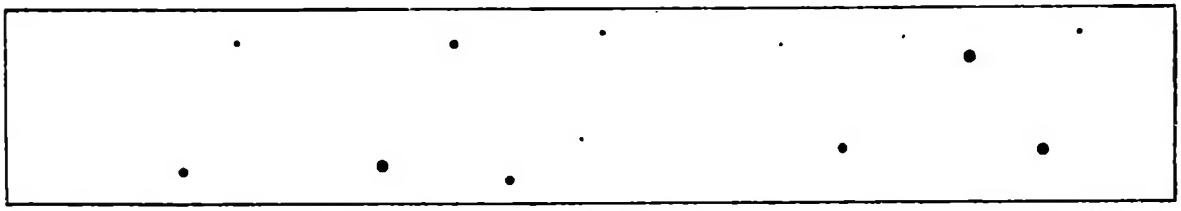
RADIOGRAPHIC REQUIREMENTS

AWS-ASTM Classification	Radiographic Standard[a,b]
E7015	Grade I
E7016	Grade I
E7018	Grade I
E6020	Grade I
E7028	Grade I
E6010	Grade II
E6011	Grade II
E6013	Grade II
E7014	Grade II
E7024	Grade II
E6027	Grade II
E6012	Not required

[a] See Figure 3

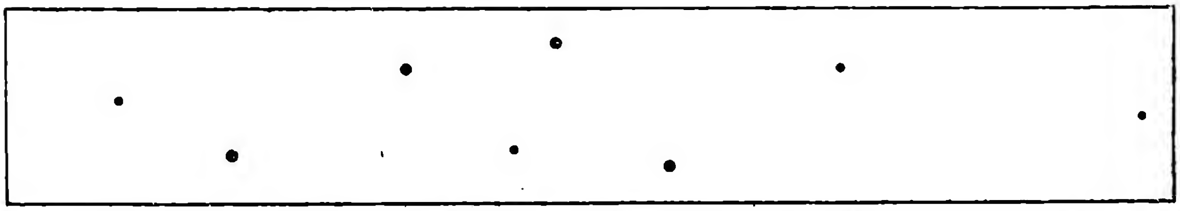
[b] The radiographic quality obtainable under the actual industrial conditions employed for the various electrode classifications is discussed in A1.11 Radiographic Quality of Welds in Appendix A1.

GRADE I



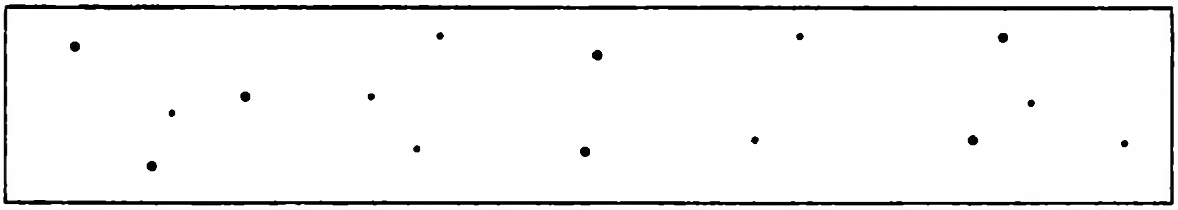
ASSORTED POROSITY

Size of Porosity - 1/64 to 1/16 in. in diameter. Maximum number of indications in any 6 in of weld = 15



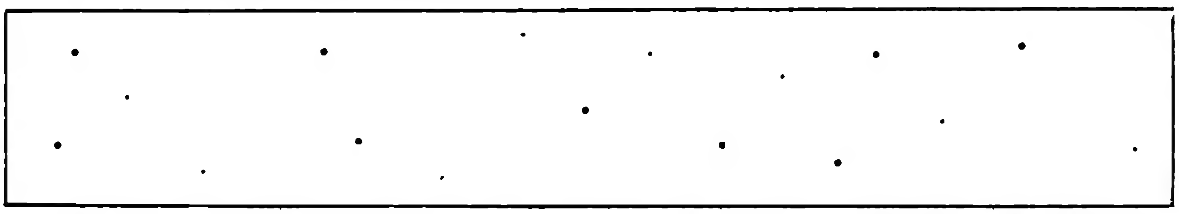
LARGE POROSITY

Size of Porosity - 3/64 to 1/16 in. in diameter. Maximum number of indications in any 6 in. of weld = 8



MEDIUM POROSITY

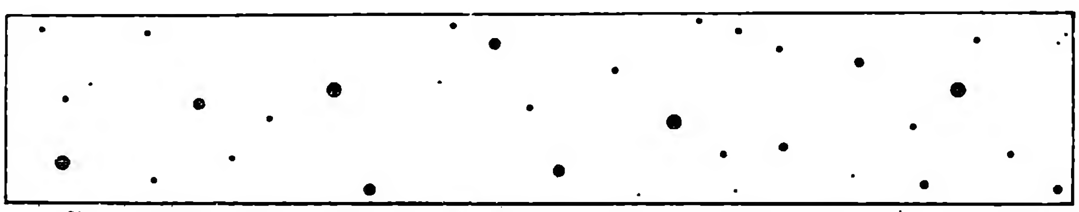
Size of Porosity - 1/32 to 3/64 in. in diameter. Maximum number of indications in any 6 in of weld = 15



FINE POROSITY

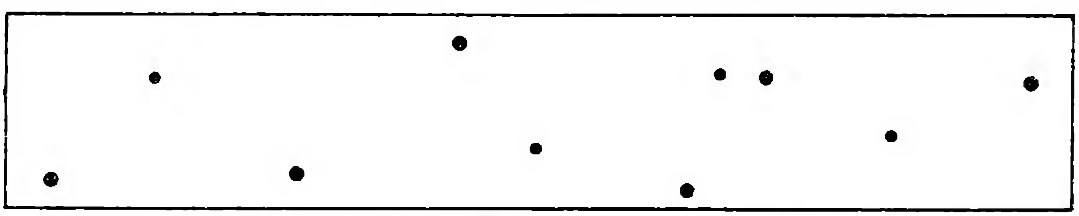
Size of Porosity - 1/64 to 1/32 in. in diameter. Maximum number of indications in any 6 in. of weld = 20

GRADE II



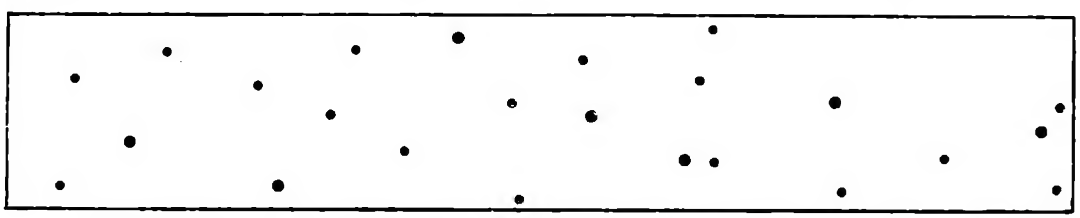
ASSORTED POROSITY

Size of Porosity - 1/64 to 5/64 in. in diameter. Maximum number of indications in any 5 1/2 in. of weld = 38



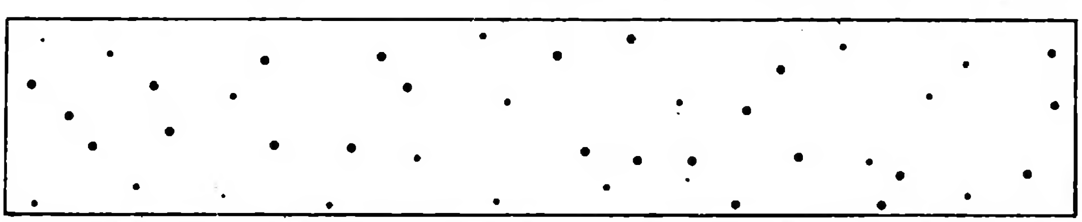
LARGE POROSITY

Size of Porosity - 1/16 to 5/64 in. in diameter. Maximum number of indications in any 5 1/2 in. of weld = 10



MEDIUM POROSITY

Size of Porosity - 3/64 to 1/16 in. in diameter. Maximum number of indications in any 5 1/2 in. of weld = 24



FINE POROSITY

Size of Porosity - 1/64 to 3/64 in. in diameter. Maximum number of indications in any 5 1/2 in. of weld = 48

MILD STEEL ELECTRODES

MINIMUM TENSILE STRENGTH AND DUCTILITY REQUIREMENTS

FOR ALL-WELD-METAL TENSION TEST

IN THE AS-WELDED CONDITION[b]

TABLE 4

AWS-ASTM CLASSIFICATION	TENSILE STRENGTH Min, Psi	YIELD POINT, Min, Psi	ELONGATION in 2 in., Min %
E60 series:[c]			
E6010	62,000	50,000	22
E6011	62,000	50,000	22
E6012	67,000	55,000	17
E6013	67,000	55,000	17
E6020	62,000	50,000	25
E6027	62,000	50,000	25
E6030	62,000	50,000	25
E70 series:[d]			
E7014	72,000	60,000	17
E7015	72,000	60,000	22
E7016	72,000	60,000	22
E7018	72,000	60,000	22
E7024	72,000	60,000	17
E7028	72,000	60,000	22

[b] See Table 8 for sizes to be tested. (A.S.T.M. designation A-233-64T)

[c] For each increase of one percentage point in elongation over the minimum, the yield point or tensile strength or both may decrease 1,000 psi to a minimum of 60,000 psi for the tensile strength and 48,000 psi for the yield point.

[d] For each increase of one percentage point in elongation over the minimum, the yield point or tensile strength or both may decrease 1,000 psi to a minimum of 70,000 psi for the tensile strength and 58,000 psi for the yield point.

TABLE 5

IMPACT PROPERTY REQUIREMENTS[a]

AWS-ASTM Classification	Minimum V-Notch Impact Requirement[b]
E6010, E6011	20 Ft-Lb at -20 F
E6027, E7015	
E7016, E7018	
E7028	20 Ft-Lb at 0 F
E6012, E6013	Not required
E6020, E7014	
E7024	

[a]See Table A3 in Appendix A1 for Metric Equivalents.

[b]The extreme lowest value obtained together with the extreme highest value shall be disregarded for this test. Two of the three remaining values shall be greater than the specified 20 ft-lb energy level; one of the three may be lower but shall not be less than 15 ft-lb. The computed average value of the three remaining values shall be equal to or greater than the 20 ft-lb energy level.

AWS-ASTM Classification	Electrode: Current and Polarity	Electrode: Size	Radiographic Test,[b,c] All-Weld-Metal Tension Test[b,d]	Impact Test[b,e]
E6010	dc, reverse polarity	3/32, 1/8	not req'd	not req'd
		5/32, 3/16	F	F
		7/32	not req'd	not req'd
		1/4	F	F
		5/16	F	not req'd
E6011	ac and dc, reverse polarity	3/32, 1/8	not req'd	not req'd
		5/32, 3/16	F	F
		7/32	not req'd	not req'd
		1/4	F	F
		5/16	F	not req'd
E6012	ac and dc, straight polarity	1/16 to 1/8, incl.	not req'd	not req'd
		5/32, 3/16	F[h]	not req'd
		7/32	not req'd	not req'd
		1/4	F[h]	not req'd
		5/16	F[h]	not req'd
E6013	ac and dc, both polarities	1/16 to 1/8 incl.	not req'd	not req'd
		5/32, 3/16	F[g]	not req'd
		7/32	not req'd	not req'd
		1/4	F[g]	not req'd
		5/16	F[g]	not req'd
E7014	ac and dc, both polarities	3/32, 1/8	not req'd	not req'd
		5/32	F[g]	not req'd
		3/16	F[g]	not req'd
		7/32	not req'd	not req'd
		1/4	F[g]	not req'd
		5/16	F[g]	not req'd
E7015	dc, reverse polarity	3/32, 1/8	not req'd	not req'd
		5/32	F	F
		3/16	F	F
		7/32	not req'd	not req'd
		1/4	F	F
		5/16	F	not req'd
E7016	ac and dc, reverse polarity	3/32, 1/8	not req'd	not req'd
		5/32	F	F
		3/16	F	F
		7/32	not req'd	not req'd
		1/4	F	F
		5/16	F	not req'd
E7018	ac and dc, reverse polarity	3/32, 1/8	not req'd	not req'd
		5/32	F	F
		3/16	F	F
		7/32	not req'd	not req'd
		1/4	F	F
		5/16	F	not req'd
E6020	For H-Fillets—ac and dc, straight polarity. For Flat Position—ac and dc, both polarities	1/8	not req'd	not req'd
		5/32, 3/16	F[g]	not req'd
		7/32	not req'd	not req'd
		1/4	F[g]	not req'd
		5/16	F[g]	not req'd
E7024	ac and dc, both polarities	3/32, 1/8	not req'd	not req'd
		5/32, 3/16	F[g]	not req'd
		7/32	not req'd	not req'd
		1/4	F[g]	not req'd
		5/16	F[g]	not req'd
E6027	For H-Fillets—ac and dc, straight polarity. For Flat Position—ac and dc, both polarities	1/8	not req'd	not req'd
		5/32, 3/16	F[g]	F[g]
		7/32	not req'd	not req'd
		1/4	F[g]	F[g]
		5/16	F[g]	not req'd
E7028	ac and dc, reverse polarity	1/8	not req'd	not req'd
		5/32, 3/16	F	F
		7/32	not req'd	not req'd
		1/4	F	F

[a] For electrodes smaller than 5/32 in. and for the 7/32-in. size, the specified tests wo tailed modification; such sizes may be judged from the results of tests on the 5/32- a respectively.

[b] The abbreviations F, H, V, and OH are defined in footnote *a* of Table 1.

[c] See 8.1.1 and 21. Radiographic Test.

[d] See 8.1.2 and 22. All-Weld-Metal Tension Test.

[e] See 8.1.3 and 23. Impact Test.

[f] See 8.1.4 and 24. Fillet Weld Test.

[g] Direct current, straight polarity only, may be used where dc, both polarities, is

[h] No radiographic test is required for this classification.

SELECTING THE RIGHT ELECTRODE

Picking the right electrode is a matter of analyzing the conditions applying to a particular job and then determining the type and size of electrode best suited to those conditions. Such an analysis is made easier if a practice is made of always checking the following factors:

1) What is the base metal to be welded?
2) Dimensions of the section to be welded.
3) What type of current is available?
4) What welding position, or positions, will be used?
5) What sort of fitup does the work permit?
6) Must weld deposit possess any specific properties such as corrosion resistance, high tensile strength, ductility, etc?
7) Must weld meet requirements of any code, standard, or specification such as ASME boiler code, government specifications, etc.?

After carefully checking the above factors the operator should have no difficulty in picking an Airco electrode which will provide the arc stability, smoothness of bead, easy slag removal, and minimum spatter which are so essential to fast, top-quality arc welding.

TESTING ELECTRODES FOR MECHANICAL PROPERTIES

The all-weld-metal tension test, sometimes called the "0.505 tension test," serves to provide fundamental data on the strength and ductility of the weld metal. The tests may be conducted on "as-welded" or stress-relieved specimens thus providing additional information. The data may not be representative of fabrication practice, but rather of a standard set of conditions for purposes of electrode classification. A special joint design is used to minimize dilution. Welding variables and cooling rates are controlled. The usability of electrodes is generally checked by means of fillet weld usability test.

Other tests to determine special properties of weld metal such as notch toughness and soundness of deposit are often re-

quired by AWS, ASME Military Specifications. Each specification outlines the tests that weld metal from each electrode type must pass in order to conform to that particular specification.

ELECTRODE CONFORMANCE AND APPROVALS

Many applications of metal arc welding are performed in accordance with some industry code or specification or under the requirements of government specification. Such industry codes are the ASME Boiler and Pressure Vessel Code, the ASA Code for Pressure Piping, the AWS Standard Code for Arc and Gas Welding in Building Construction. Government specifications, formerly issued by several departments, are now in the form of coordinated military (MIL) specifications which are used for procurement by all agencies of the Department of Defense.

In general industry specifications do not involve approval of electrodes prior to submission on bid or for the work. Therefore, conformance of electrodes to industry specifications is determined by the supplier on the basis of regular testing. Most of the military and government specifications require approval of electrodes, on the basis of specified tests, prior to submission of bids. The requirement for testing samples from each production lot is becoming more common for military and nuclear applications.

The American Welding Society (AWS) has published a series of specifications designed to cover the various filler metals. Already available are specifications for mild steel, low alloy steels, stainless steel, copper and copper alloy, aluminum and aluminum alloy electrodes. Other specifications covering electrodes for hard facing and for welding cast iron have been published by these groups. It is important to note that the classification designations established by the AWS specifications are generally used, and have essentially the same significance, in most of the other industry and government specifications.

AIRCO CONFORMANCE TO AMERICAN BUREAU OF SHIPPING (ABS) AND UNITED STATES COAST GUARD (USCG) MILD AND LOW ALLOY STEEL COVERED ELECTRODES SPECIFICATIONS

MILD STEEL

ABS TYPE	AIRCO ELECTRODE	ABS CERTIFICATE NO.
E6010	6010	66-BA-3785
E6011	6011	66-BA-3830
E6011	6011C	66-BA-3829
E6012	6012	BA-626
E6012	6012C	BA-842-B
E6013	6013	66-BA-3741
E6013	6013C	66-BA-3740
E6020	6020	66-BA-3751
E6020	6020D	66-BA-3752
E6027	EASYARC 6027	66-BA-3826
E7014	EASYARC 7014	66-BA-3827
E7016	7016	66-BA-3831
E7016	7016M	66-BA-3767
E7018	EASYARC 7018MR	66-BA-3768
E7018	EASYARC 7018C	64-BA-3232
E7018	CODE-ARC 7018MR	67-BA-4028
E7024	EASYARC 7024	66-BA-3769
E7028	EASYARC 7028	66-BA-3824

LOW ALLOY STEEL

E7010-A1	7010-A1	66-BA-3756
E7020-A1	7020-A1	66-BA-3757
E8016-B2	8016-B2	66-BA-3828
E8016-C1	8016-C1	66-BA-3720
E8016-C3	8016-C3	66-BA-3832
E9016-B3	9016-B3	66-BA-3811
E11018M	CODE-ARC 11018M	66-BA-4293

The United States Coast Guard (USCG) accepts American Bureau of Shipping (ABS) approvals.

AIRCO CONFORMANCE TO MILITARY SPECIFICATIONS FOR MILD AND LOW ALLOY STEEL COVERED ELECTRODES

MIL TYPE	AIRCO ELECTRODE	SPECIFICATION NO.
6010 or G6010	6010*	QQ-E-450 (Latest Revision)
6011 or G6011	6011*	QQ-E-450 (Latest Revision)
6012	6012	QQ-E-450 (Latest Revision)
6013	6013	QQ-E-450 (Latest Revision)
6020	6020	QQ-E-450 (Latest Revision)
6027	EASYARC 6027	QQ-E-450 (Latest Revision)
7024	EASYARC 7024	QQ-E-450 (Latest Revision)
7010-A1	7010-A1	MIL-E-22200/7 (Latest Revision)
7016	7016M	MIL-E-22200/6 (Latest Revision)
7018	CODE-ARC 7018	MIL-E-0022200/1 (Latest Revision)
7020-A1	7020-A1	MIL-E-22200/7 (Latest Revision)
8016	8016-C3	MIL-E-22200/6 (Latest Revision)
8016C3	8016-C3	MIL-E-22200/6 (Latest Revision)
8018-C3	CODE-ARC 8018-C3	MIL-E-0022200/1 (Latest Revision)
11018	CODE-ARC 11018	MIL-E-0022200/1 (Latest Revision)
10016	10016-G	MIL-E-22200/6 (Latest Revision)
8016-B2	8016-B2	MIL-E-22200/8 (Latest Revision)
9016-B3	9016-B3	MIL-E-22200/8 (Latest Revision)

*Has been qualified for use on galvanized as well as black plate mild steel

"Conformance to" does not necessarily indicate that an electrode will automatically meet all requirements of a given MIL specification. To be qualified as a supplier to the government each manufacturing or sales organization must submit his product to the proper government agency for approval. Upon approval the product, manufacturer and sales outlet may be registered and included in the "QPL". QPL refers to the military "Qualified Products List" of any given MIL specification. However, each specification has its own testing and acceptance requirements. The costs incurred in the performance of these tests will be charged to the customer when applicable. In effect, Airco is requalifying, certifying and guaranteeing each lot of our electrodes to our customers in accordance with the terms and conditions of the MIL specification. Specify on your order if MIL certification is required.

AWS FILLER METAL SPECIFICATIONS

(These Specifications are available from the American Welding Society, Inc., 345 E. 47th Street, New York, New York 10017.)

Specification for:

	AWS DESIGNATION	ASTM DESIGNATION
Mild Steel Covered Arc-Welding Electrodes	A5.1	A 233
Iron and Steel Gas-Welding Rods	A5.2	A 251
Aluminum and Aluminum-Alloy Arc-Welding Electrodes	A5.3	B 184
Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes	A5.4	A 298
Low-Alloy Steel Covered Arc-Welding Electrodes	A5.5	A 316
Copper and Copper-Alloy Arc-Welding Electrodes	A5.6	B 225
Copper and Copper-Alloy Welding Rods	A5.7	B 259
Brazing Filler Metal	A5.8	B 260
Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes	A5.9	A 371
Aluminum and Aluminum-Alloy Welding Rods and Bare Electrodes	A5.10	B 285
Nickel and Nickel-Alloy Covered Welding Electrodes	A5.11	B 295
Tungsten Arc-Welding Electrodes	A5.12	B 297
Surfacing Welding Rods and Electrodes	A5.13	A 399
Nickel and Nickel-Alloy Bare Welding Rods and Electrodes	A5.14	B 304
Welding Rods and Covered Electrodes for Welding Cast Iron	A5.15	A 398
Titanium and Titanium-Alloy Bare Welding Rods and Electrodes	A5.16	B 382
Bare Mild Steel Electrodes and Fluxes for Submerged-Arc Welding	A5.17	A 558
Mild Steel Electrodes for Gas Metal-Arc Welding	A5.18	A 559
Magnesium-Alloy Welding Rods and Bare Electrodes	A5.19	B 448
Mild Steel Electrodes for Flux-Cored Arc Welding	A5.20	
Composite Surfacing Welding Rods and Electrodes	A5.21	

The essential features of several of the codes and specifications are summarized herewith:

ASME BOILER AND PRESSURE VESSEL CODE

This specification now employs classifications substantially the same as those provided in the AWS filler metal specifications. In addition, electrodes are further identified by "Electrode Group Numbers" and "Weld Metal Analysis Numbers." These group and analysis numbers are identified for each electrode, where applicable. Acceptance of electrode is based upon the electrode manufacturer's statement of certification of conformance. It is the responsibility of each manufacturer or contractor to organize his welding operations and conduct the necessary tests so that the requirements of the code are fulfilled.

ASA CODE FOR PRESSURE PIPING

Acceptance of electrodes is based upon the electrode manufacturer's statement of certification of conformance.

U.S. DEPARTMENT OF DEFENSE

It is required that electrodes be approved, prior to use on the basis of established specifications. Currently the Navy, the Army, and the Air Force are changing to the use of military specifications (MIL) issued by the Naval Ship Engineering Center.

U.S. COAST GUARD

Approvals granted by American Bureau of Shipping or U.S. Navy Department are acceptable to the U.S. Coast Guard.

AMERICAN BUREAU OF SHIPPING

It is required that electrodes be approved, prior to use, based upon the established specifications of this organization. These specifications follow closely the AWS filler metal specifications and employ the same classification numbers.

STRUCTURAL STEEL WELDING

Method of approval is dependent upon the building code of the city or town involved. Most codes recognize the AWS Filler Metal Specifications and will accept a statement of conformance thereto. Pittsburgh still requires prior approval in terms of older filler metal specifications.

AWS ELECTRODE CLASS (a)

	E6010	E6011	E6012	E6013	E7014	E7016	E7018	E6020	E7024	E6027	E7028
Groove butt welds, flat (>¼in.)	4	5	3	8	9	7	9	10	9	10	10
Groove butt welds, all positions (>¼in.)	10	9	5	8	6	7	6	(b)	(b)	(b)	(b)
Fillet welds, flat or horizontal	2	3	8	7	9	5	9	10	10	9	9
Fillet welds, all positions	10	9	6	7	7	8	6	(b)	(b)	(b)	(b)
Current (c)		AC	DCS	AC	AC	DCR	DC	DC	AC	AC	DCR
	DCR	DCR	AC	DC	DC	AC	AC	AC	DC	DC	AC
Thin material (<¼in.)	5	7	8	9	8	2	2	(b)	7	(b)	(b)
Heavy plate or highly restrained joint	8	8	6	8	8	10	9	8	7	8	9
High-sulfur or off-analysis steel	(b)	(b)	5	3	3	10	9	(b)	5	(b)	9
Deposition rate	4	4	5	5	6	4	6	6	10	10	8
Depth of penetration	10	9	6	5	6	7	7	8	4	8	7
Appearance, undercutting	6	6	8	9	9	7	10	9	10	10	10
Soundness	6	6	3	5	7	10	9	9	8	9	9
Ductility	6	7	4	5	6	10	10	10	5	10	10
Low-temperature impact strength	8	8	4	5	8	10	10	8	9	9	10
Low spatter loss	1	2	6	7	9	6	8	9	10	10	9
Poor fit-up	6	7	10	8	9	4	4	(b)	8	(b)	4
Welder appeal	7	6	8	9	10	6	8	9	10	10	9
Slag removal	9	8	6	8	8	4	7	9	9	9	8

(a) Rating is on a comparative basis of same size electrodes with 10 as the highest value. Ratings may change with size.

(b) Not recommended.

(c) DCR-direct current reverse, electrode positive; DCS-direct current straight, electrode negative; AC-alternating current; DC-direct current, either polarity.

DEPOSITION RATES
(Pounds Per Hour)

AWS Class	Position Welding	3/16"	7/32"	1/4"
E7028	F & H	8.5	10.0	13.1
E6027	F & H	9.0	11.3	13.5
E7024	F & H	9.0	10.8	12.2
E7014	All	6.4	7.8	8.8
E7018	All	5.7	7.3	8.8
E7016	All	4.2	5.0	6.5
E6013	All	4.4	5.3	6.6
E6011	All	4.2	4.9	6.0
E6010	All	4.0	4.8	6.0

Average welding conditions in the flat and horizontal positions.

Deposition rates should be reduced for vertical welding and in some cases may be increased when welding in the flat position.

Advantages of Iron Powder Types:

Ease of slag removal
High Speeds
Better mechanical properties
Ease of welding

Advantages of Conventional Types:

Durable bond coating
Deeper penetration
Better performance in the vertical and overhead position

When selecting electrodes consideration must be given to the position of the weldment, the material thickness, the quality required for code conformance, if any, the weld profile, penetration, etc.

COMPARISON ELECTRODE TYPES - DEPOSITION RATE AND FILLET LENGTH

3/16 inch Diameter Electrodes

AWS Class	Type Current	Optimum Amperes	Coating O.D.	Inches Lb.	Dep. Eff %	Burn Off In/Min.	Dep, Rate Lbs/Hr.	1/4" Horizontal Fillets			
								Lgth/Elec.	Length	Time	In/Min
E-6010	DCR	175	.240"	116	76.5	9.30	3.70	12"	7"	1.32	5.30
E-6010	DCR	175	.255"	109	79.5	9.20	3.97	12"	7-1/2"	1.30	5.77
E-6011	AC	175	.240"	114	74.0	10.20	4.00	12"	7"	1.26	5.53
E-6011	AC	175	.250"	111	76.0	10.25	4.30	12"	7-1/4"	1.20	6.02
E-6012	AC	225	.238"	112	77.0	10.20	4.40	12"	8"	1.15	6.95
E-6012	AC	225	.238"	112	78.0	10.00	4.20	12"	7-1/2"	1.20	6.25
E-6013	AC	225	.250"	109	74.0	9.8	4.00	12"	9"	1.23	7.32
E-6020	AC	225	.270"	100	71.0	13.0	5.50	12"	8-1/2"	.96	8.85
E-7016	AC	225	.280"	94	69.0	8.7	3.80	12"	8"	1.38	5.80
E-7018	AC	240	.297"	90.5	77.0	11.20	5.75	12"	8-1/2"	1.25	6.80
E-7028	AC	275	.380"	60.5	71.5	10.40	7.50	12"	12"	1.27	9.45
E-7014	AC	250	.300"	85.5	73.0	11.00	5.50	12"	10"	1.20	8.32
E-7024	AC	275	.390"	58	70.0	13.50	9.70	12"	13"	.99	13.12
E-6027	AC	275	.390"	62	72.5	12.30	9.50	12"	13"	.97	13.40

A.W.S. - A.S.T.M. Class. E6010

DEPOSITION RATES

DIRECT CURRENT - REVERSE POLARITY						
DIAMETER	AMPERES	IN./LB.	DEP. EFF.	BURN OFF RATE IN./MIN.	MELT. RATE #/HR.	DEP. RATE #/HR.
1/8"	85	245	82.5	8.30	2.04	1.68
	100		79.5	10.56	2.60	2.07
	115		76.8	11.45	2.82	2.17
5/32"	120	163	83.7	9.70	3.57	2.99
	135		81.6	9.95	3.64	2.97
	150		75.9	10.00	3.68	2.79
3/16"	160	113	81.5	8.45	4.44	3.63
	175		78.2	9.50	4.98	3.89
	190		76.2	9.75	5.16	3.93

A.W.S. - A.S.T.M. CLASS. E7016

DEPOSITION RATES

DIRECT CURRENT - REVERSE POLARITY						
DIAMETER	AMPERES	VOLTAGE	DEP. EFF.	IN./MIN.	MELT. RATE #/HR.	DEP. RATE #/HR.
1/8"	120	20-22	64.6	11.00	3.38	2.18
5/32"	165	22-24	66.0	10.40	4.82	3.18
3/16"	255	22-24	62.5	9.76	6.37	3.98
7/32"	260	24-26	65.6	8.26	7.23	4.75
1/4"	300	26-28	63.2	7.46	8.76	5.55
ALTERNATING CURRENT						
1/8"	130	20-22	63.5	11.10	3.40	2.16
5/32"	175	22-24	65.0	10.17	4.70	3.06
3/16"	240	22-24	65.0	8.90	5.82	3.78
7/32"	280	24-26	66.4	8.44	7.39	4.90
1/4"	330	26-28	63.3	8.11	9.52	6.03

A.W.S. - A.S.T.M. CLASS E7018

DEPOSITION RATES

DIRECT CURRENT - REVERSED POLARITY							
DIAMETER	IN./LB.	AMPERES	ARC VOLTS	DEP. EFF.	IN./MIN.	MELT. RATE #/HR.	DEP. RATE #/HR.
1/8"	173.2	100 120	22-24	73.8 72.8 72.0	9.70 10.65 11.45	3.36 3.68 3.96	2.48 2.68 2.88
5/32"	124.5	140 160 180	22-24	77.2 76.0 75.9	8.80 10.00 11.10	4.24 4.81 5.34	3.27 3.65 4.06
3/16"	90.4	185 210 240	22-24	76.2 75.9 74.2	8.90 9.42 10.70	5.92 6.25 7.10	4.51 4.75 5.26
7/32"	66.7	270 300 325	24-26	77.8 76.6 76.0	8.80 9.42 9.94	7.90 8.47 8.94	6.15 6.44 6.85
1/4"	52.5	300 330 360	24-26	78.8 78.0 76.6	8.30 8.95 9.65	9.49 10.20 11.00	7.46 7.94 8.42

The above deposition rates were obtained from tests conducted on horizontal fillet welds.

DEPOSITION RATES

ALTERNATING CURRENT						
DIAMETER	AMPERES	IN./LB.	DEP. EFF	IN./MIN.	MELT. RATE #/HR.	DEP. RATE #/HR.
1/8"	125 150 165	133.3 134.0 134.0	68.8 68.5 67.0	10.1 12.5 14.3	4.53 5.60 6.39	3.11 3.84 4.27
5/32"	175 225 250	84.5 84.5 84.5	68.5 67.2 66.6	9.31 12.65 14.7	6.68 8.98 10.4	4.54 6.02 6.95
3/16"	225 250 300	60.0 59.8 59.4	69.0 68.1 68.0	9.65 10.8 13.53	9.65 10.85 13.68	6.66 7.40 9.28
7/32"	265 300 350	47.1 47.1 47.4	69.3 69.1 68.8	9.01 10.45 12.4	11.5 13.3 15.7	7.94 9.23 10.8

COST OF DEPOSITED METAL

3/16" diameter electrodes, flat position, average conditions

Assume 60% duty cycle (arc time) labor cost of \$3.00 per hour
Overhead of 100% or \$3.00 per hour

20% stub loss deposition efficiency as noted.

$$\frac{\text{Labor cost plus overhead}}{\text{Duty cycle x deposition rate}} + \text{Filler metal cost per lb.} = \text{cost per lb. of deposited metal}$$

Example: E6010 deposition rate = 4.0 lbs. per hour, Filler metal .21 per lb.

$$\frac{3.00 + 3.00}{.60 \times 4.0} + .21 = \$2.71 \text{ per lb. deposited metal}$$

ASTM-AWS	DEPOSITION RATE LBS./ARC HOUR	DEPOSITION EFFICIENCY	ELECTRODE COST PER LB.	FILLER METAL COST PER LB.	DEPOSITED METAL COST PER LB.
E6010	4.0	76%	$ .13	$ .21	$ 2.71
E6013	4.4	74%	.13	.23	2.50
E7016	4.2	66%	.15	.28	2.66
E7018	5.7	75%	.17	.28	2.03
E7014	6.4	75%	.13	.22	1.78
E7024	8.5	68%	.14	.26	1.44
E6027	9.0	68%	.14	.26	1.37
E7028	8.5	68%	.20	.37	1.55

WELDING PROCEDURES FOR MILD STEEL ELECTRODES

For best results a medium-long arc should be maintained. This will result in good wetting and puddling of the deposit to permit gases to escape, thereby controlling the shape and appearance of the weld. Flat and horizontal fillets are best made with the electrode held at an angle of 45° to each plate and manipulated slightly back and forth in the direction of travel. This is to assure that proper penetration is obtained on the forward sweep, and that undercut and bead shape is controlled on the backward sweep in the crater.

For root passes in vertical fillet or butt welds, the electrode is held perpendicular to the root of the joint and tilted slightly in the direction of travel. When traveling up the joint, it may be necessary at high current settings to "whip" the electrode in the direction of travel. The arc should be long enough so that no metal is deposited at the top of the whip, and then shortened when back in the crater to deposit and spread the molten metal, controlling bead size and undercut.

Overhead fillet and butt welds are made in much the same way as horizontal fillet welds, except that oscillation in the direction of travel may require a longer sweep to permit the molten crater to set up.

For multiple-pass horizontal or overhead welds, stringer beads or narrow weaves are recommended, with wider weaves employed for vertical-up welding. The root pass of a vertical-down weld is made with straight travel and without weave or whip. The arc force is directed upward to hold the puddle in place. A weave may be used on subsequent passes vertically down.

In the Airco Electrode Pocket Guide under "specifications" for each electrode are recommended operating amperage for each electrode size. In general, welding below these amperages will produce porosity, while spatter and poor deposition efficiencies are evident at higher amperages.

WELDING PROCEDURES FOR LOW HYDROGEN AND LOW ALLOY ELECTRODES

The manipulation techniques or procedures for using all low hydrogen electrodes are basically the same. The various alloy additions do not affect the operating characteristics of the electrodes. Slightly higher current settings will be used for the iron powder low hydrogen types (XX18) than for the low hydrogen electrodes without iron powder (XX16) of the same diameter.

Unlike the procedure for mild steel electrodes where a medium-long arc is recommended, with low hydrogen and low alloy electrodes as short an arc as possible should be kept at all times. A slight weave may be used to control the size and shape of the weld deposit. On multipass welds all slag should be removed between passes. The electrode is usually tilted slightly in the direction of travel.

DOWN HAND

Flat position welds should be made on the high end of the recommended current range for each electrode size to insure good "wash up" on the sides. A weave of 2½ times the electrode diameter may be used. On larger size grooves several stringer beads should be used in preference to one large weave bead.

VERTICAL

The root pass should be made with a straight upward progression, a short arc, the electrode tilted slightly in the direction of travel. The electrode must not be "whipped" or manipulated in any way to increase arc length. Some welders prefer to use a "V" shape motion for vertical up root passes. The electrode should hesitate at the point of the "V" in the root of the joint to assure penetration and dig out slag. Each leg of the "V" should be about 1/8 inch. It should be reiterated, no "whipping" should be done. On larger size vertical welds the second and subsequent passes should be made by weaving across the face of the root bead, continuously building up a shelf. The weave should pause at the sides of the first pass to wash against the base metal and clear out trapped slag.

OVERHEAD

Stringer beads are recommended for all overhead welding. Overhead fillets should be made with the electrode at an angle of 30° to the vertical leg.

HORIZONTAL

Horizontal fillets should be made with stringer beads, with the electrode directed into the joint at a 45° angle. Stringer beads should also be used for multi-pass welds.

ELECTRODE GROUPING

The A.S.M.E. Code in Section IX (Table Q 11.2) has set up four basic groups for mild steel and low alloy electrodes. The grouping is determined by the electrode coating and has been assigned group numbers F1, F2, F3 and F4. A welder making a performance qualification with F4 group electrodes will automatically be qualified to use all of the other lower numbered groups. This does not apply to procedure qualifications, however. Procedure qualification must be made for each group of electrodes.

Second in importance in terms of electrode consumption, but first in popularity with welders, is ASME group F3. This group is composed of electrodes E-6010 and E-6011. The E-6010 electrode has a sodium cellulose coating. The cellulose is used to provide a gaseous shield while the sodium provides characteristics desirable on DC current operation. The E-6011 electrode coating is the same except for the addition of the easily ionized material necessary to AC current operation. Obviously some of the operational characteristics for DC Current must be sacrificed however. The AC E-6011 electrode will produce welds of higher yield strength and slightly more ductility than the E-6010 electrode. These electrodes are fully ASME approved and also have unlimited American Bureau of Shipping approval within their physical range. These are the only electrodes ABS approved for welding galvanized steel.

Recently a few electrode manufacturers have produced these electrodes with small amounts of iron powder added to the coatings with some improvement to their operating characteristics and less spatter loss. Operating characteristics of the AC iron powder electrodes are greatly improved on DC Current compared to previous AC electrodes. The problem of moisture pick-up is increased however.

The group of electrodes ranking highest in consumption is the F2 group. The parent of this group is the very popular straight polarity E-6012 electrode. To produce this electrode, the cellulose of the E-6010 class is largely removed and replaced with titania. This produces a heavy slag, thus permitting higher

current values and resulting in faster deposit rates. This electrode is not suited for X-ray quality welding and should be used for work requiring only spot X-ray, where the standards are most more liberal. The American Bureau of Shipping code limits the use of this electrode to non-strength members only. They are very popular, however, in single pass structural steel welding but are being replaced in many places by either E-6013 or iron powder electrodes. The increasingly popular E-6013 electrode is the AC equivalent of its E-6012 parent. It will also operate very well on DC straight polarity. Its modification is made by adding potassium silicate to the coating. The coating will then be titania potassium. You will notice a pattern formed; each DC electrode coating contains sodium, and each AC electrode coating contains potassium. The other coating elements are changed to produce whatever characteristics are desirable. Some E-6013 electrodes are made to weld very light gauges; due to the additional coating elements that ionize easily, they are more stable at low currents.

The E-7014 electrode has basically the lime coating as its parent E-6013, except for the addition of 30% iron powder to permit higher current values and greater deposition rates. This electrode is labeled all position but is limited in the vertical and overhead positions due to the heavy coating. The E-6013 and E-7014 class of electrodes produce welds with better physical properties and less inclusions than the E-6012 electrodes, however these classes are not generally considered useful for multiple pass X-ray quality work as there are too many better electrodes to choose from.

The group of electrodes third in consumption importance is group F1. The E-6020 electrode is the parent of this group and this electrode, or the iron powder modifications, is the best electrode available for X-ray quality welds on medium and heavy plate at high speeds. They are suitable for downhand welding only, due to the heavy slag. The electrodes in this class include: the E-6020 and E-6027, which have the same coating except for the addition of 50% iron powder; the E-7024 titania, 50% iron powder electrode (for fillet welds), and the low hydrogen modification E-7023, which has 50% iron powder also.

The fourth group and growing in terms of consumption, is the low hydrogen group F4. (These electrodes are classes E-7015, E-7016 and E-7018, that is the DC only, the AC-DC and the AC-DC iron powder). The E-7018 coating has 30% iron powder added to a basic E-7016 coating. The low hydrogen electrodes have characteristics similar to stainless steel electrodes due to the lime type coatings. The lime is used to produce a low hydrogen CO_2 atmosphere. The weld metal produced by the use of low hydrogen electrodes are valuable for welding heavy, highly stressed sections where preheat would otherwise be required, or to reduce preheat requirements. They may also be used to reduce the preheat requirements of the hardenable steels.

Low hydrogen electrodes are intended to be used on steels difficult to weld with conventional electrodes. All of the low hydrogen group of electrodes produce X-ray quality welds and bear unlimited ASME, and ABS approval. The impact properties of the weld metal produced by low hydrogen electrodes are superior at low temperatures. The class E-6010, E-6011 and E-6020 produce good impact porperties while the F2 group, the E-6012, E-6013, E-7014 and also the E-7024 electrodes produce rather low impact properties at low temperatures.

The alloying elements in the low alloy electrodes are usually added to the weld metal from the electrode coating. It is cheaper to purchase a common core wires rather than expensive special wires. It is not at all difficult to transfer alloying materials across the arc. It makes little difference whether the alloying element is obtained from the core wire or coating as approximately the same percentages can be transferred in either case.

MILD STEEL

ELECTRODE GROUPING

AWS-ASME GROUPING	AWS-ASTM		COATING TYPE	X-RAY QUALITY
F3	E-6010	Sodium)	Cellulose	OK
	E-6011	Potassium)		
F2	E-6012	Sodium)		Not
	E-6013	Potassium)	Titania	Rec.
	E-7014	30% Iron Powder)		
F4	E-7015	Sodium Lime)		OK
	E-7016	Potassium Lime)	Low	
	E-7018	30% Iron Powder)	Hydrogen	
F1	E-6020	Heavy Mineral)	Mineral	
	E-6027	Add 50% Iron Powder)	Type	OK
	E-7028	L.H. 50% Iron Powder)	Heavy	
	E-7024	Titania 50% Iron Powder)	Coated	

Group F1 - Best X-ray, limited to flat and horizontal work.

Group F2 - X-ray single pass but are inferior.

Group F3 - Best all position electrode for mild steel.

Group F4 - Low hydrogen equivalent of F3 group. Shorter arc required to prevent porosity.

1 - Procedure qualifications must be made for each group of electrodes.

2 - Performance or operator qualifications made with any F number will automatically qualify the welder for any lower F number.

3 - A procedure qualification will automatically qualify the operator who made the test.

TABLE Q-11.2
F-NUMBER GROUPING OF ELECTRODES AND WELDING RODS FOR PROCEDURE QUALIFICATION

Applicable SFA-Spec	Weld Metal Type from Table Q-11.3 (Former SA) Spec.	(A-No. Ref.)	(P-No. Ref.)	Electrode Classification Number E-XX20 E-XX24 E-XX27 E-XX28 E-XX30	E-XX12 E-XX13 E-XX14	E-XX10 E-XX11	E-XX15 E-XX16 E-XX18	Type ER	RG-XX	Electrode Plus Flux Combination	EXXS EXXU	EXXT
SFA 5.1	233	(A-1)	(P-1)	F1	F2	F3	F4	...	...	...	...	...
SFA 5.5	316	(A-2)	(P-3)	F1	F2	F3	F4	...	...	...	...	...
SFA 5.5	316	(A-3)	(P-4)	F1	F2	F3	F4	...	...	...	...	...
SFA 5.5	316	(A-4)	(P-5)	F1	F2	F3	F4	...	...	...	...	...
SFA 5.4	298	(A-4)	(P-5)				F4	...	...	...	...	...
SFA 5.4	298	(A-5)	(P-6)	Stainless Chrome Electrodes			F4	...	...	...	...	...
SFA 5.4	298	(A-6)	(P-7)				F4	...	...	...	...	...
SFA 5.4	298	(A-7)	(P-8)	Stainless Chrome Nickel Electrodes			F5	...	...	...	...	...
SFA 5.4	298	(A-8)	(P-8)				F5	...	...	...	...	...
SFA 5.2	251	(A-1)	(P-1)	...	...	...	...	...	F6	...	...	...
SFA 5.2	251	(A-2)	(P-3)	...	...	...	...	...	F6	...	...	...
SFA 5.17	558	(A-1)	(P-1)	...	...	...	...	...	...	F6	...	...
SFA 5.18	559	(A-1)	(P-1)	...	...	...	...	...	...	...	F6	...
SFA 5.20	559	(A-1)	(P-1)	...	...	...	...	...	...	...	...	F6
SFA 5.9	371	(A-4)	(P-5)	...	...	...	...	F7	...	...	...	...
SFA 5.9	371	(A-5)	(P-6)	...	...	...	...	F7	...	...	...	...
SFA 5.9	371	(A-6)	(P-7)	...	...	...	...	F7	...	...	...	...
SFA 5.9	371	(A-7)	(P-8)	...	...	...	...	F7	...	...	...	...
SFA 5.9	371	(A-8)	(P-8)	...	...	...	...	F7	...	...	...	...

NOTE 1: For procedure qualification a change from one F-Number to any other F-Number shall require requalification.

NOTE 2: Covering and filler metal types not listed above may be used but shall require separate qualification for procedure.

NOTE 3: Qualification of a welding procedure with an electrode up to and including A-5 (SFA 5.4) shall also qualify the procedure for welding with any lower A-Number weld metal of Spec. SFA 5.5 or SFA 5.1. A change in weld metal composition to a higher A-Number within the Group A-1 to A-5 shall require requalification of the procedure. Weld metal Types A-6, A-7, and A-8 shall require separate procedure qualification. (See Q-11, V-2.)

TABLE Q-11.3
CLASSIFICATION OF WELD METAL ANALYSES FOR PROCEDURE QUALIFICATION

Weld Metal Anal No.	Equivalent P-Number Ref for Plate or Pipe	Type of Weld Deposit	% Cr	% Mo	% Ni	Max % Mn	Max % Si
A-1	(P-1)	Mild Steel	...	...	...	1.60	1.00
A-2	(P-3)	Carbon-Moly	0.50 Max	0.40–0.65	...	1.60	1.00
A-3	(P-4)	Chrome-Moly (½ to 2% Cr)	0.50–2.00	0.40–0.65	...	1.50	1.00
A-3	(P-4)	Nickel-Moly	...	0.30–1.00	1.50–3.75	1.50	1.00
A-4	(P-5)	Chrome-Moly (2 to 10% Cr)	2.00–10.00	0.40–1.50	...	1.00	2.00
A-5	(P-6)	High-Alloy Martensitic	11.00–15.00	0.70 Max	...	2.00	1.00
A-6	(P-7)	High-Alloy Ferritic	11.00–30.00	1.00 Max	...	1.00	3.00
A-7	(P-8)	Chrome-Nickel Weld Metals Containing More Than 1% Ferrite	AISI Types 302–304–308–309–316–317–318 347–348–309 Mo–309 Cb				
A-8	(P-8)	Chrome-Nickel Weld Metals Which are Fully Austenitic	AISI Types 310–310 Cb–310 Mo–330				

NOTE 1: The carbon content of the above weld deposits shall not exceed 0.15 percent except for Group A-8 where carbon contents up to 0.30 percent may be used. Higher carbon weld metals shall require separate qualification.

NOTE 2: Qualification of a procedure with a weld metal type up to and including A-5 shall also qualify welding with any lower A-Number. Weld metals Number A-6, A-7, and A-8 require separate qualifications. (See Q-11, V-2.)

NOTE 3: Weld metal analyses which are not listed above but fall within the material analyses listed in the P-Number grouping shall fall within the A-Number corresponding to the P-Number listing in Table Q-11.3. Carbon restrictions (Note 1) shall apply. (See Q-11, V-2.)

NOTE 4: For submerged arc welding, qualification with A-1 shall qualify the procedure for welding with A-2 analysis types and vice versa.

NOTE 5: Weld metal analyses not listed in the above table and of compositions other than those listed in P-1 to P-8 shall require separate qualification.

RECOVERY OF ELEMENTS ACROSS THE ARC

FOR COATED ELECTRODES

Some of the more important elements and the percentages transferred across the arc are given in the table below.

Form Element	% Recovery
Ferromanganese	75
Ferrophosphorus	100
Ferrosilicon	55
Ferrochromium	95
Ferrocolumbium	70
Ferromolybdenum	97
Ferrovanadium	80
Ferrotitanium	5
Metalic nickel	100
Metalic copper	100
(Graphite) carbon	75

Note: A short arc should always be used in welding alloy steels to prevent excessive oxidation losses.

MILITARY SPECIFICATIONS: ELECTRODES

SPECIFICATIONS AND STANDARDS

Supplies used by the military are purchased on the basis of military specifications which describe quality, size, performance, and other features of the item, and state requirements for inspection, testing, packaging, and packing. Specifications may be obtained from the Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania, 19120. All branches of the armed services are handled by this department.

THE DEPARTMENT OF DEFENSE INDEX OF SPECIFICATIONS AND STANDARDS

These may be purchased from the superintendent of Documents, Washington D.C. 20402. This index is published in two parts; an Alphabetical Listing which shows specifications by item and number, and a Numberical Listing, by specification number and by type.

QUALIFIED PRODUCTS LISTS

The Defense Department's pamphlet, Provisions Governing Qualification, outlines the means by which a manufacturer's product may be tested for inclusion in the Qualified Products List (QPL). It is available through the Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania, 19120. The purpose of the Qualified Products List is to list all items which have been tested according to military specifications and which are therefore qualified for government use.

Inclusion in the Qualified Products List, however, does not excuse the manufacturer from further testing. Government contracts will consider only products on the Quality Products List, but require that each product be tested again before use, except where the following criteria pertain:

a. The time required for testing would unduly delay delivery of the supplies being purchased.

b. The cost of repetitive testing would be excessive.

c. The tests would require expensive or complicated test apparatus not commonly available.

WHAT ELECTRODE USERS MUST KNOW

Fabricating companies, new to military contracts, sometimes are stumped by military specification numbers called for in drawings. The companies are familiar with AWS electrode specifications, but they can't translate the Mil-Spec numbers into them to purchase the material to do the job. The Qualified Products List gives electrode types manufacturers designations, and companies' names and addresses, as well as the corresponding Mil-Spec numbers. Some individual manufacturers also provide cross indices of their products in terms of AWS classification number and Mil-Spec number.

Nickel and nickel alloy AWS A5.11-69

AWS CLASS.	MILITARY MIL-E-22200 3B	AWS CLASS.	MILITARY MIL-E-22200 3B
ENi-1	MIL-4N11	ENiCrFe-1	MIL-3N12
ENiCu-1	MIL-4N10	ENiCrFe-2	MIL-4N1A
ENiCu-2	MIL-8N10	ENiCrFe-3	MIL-8N12
	MIL-9N10	ENiMo-1	MIL-3N1B
ENiCu-3	MIL-3N14	ENiMo-2	MIL-3N1C
ENiCu-4	MIL-3N10	ENiMo-3 None	MIL-4N1W MIL 3N1N
ENiCr-1	MIL-4N12	None	MIL-3N1L

AWS A5.14-69

AWS CLASS.	MILITARY MIL-E-21562	AWS CLASS.	MILITARY MIL-E-21562
RNi-2	RN41	RNiCrFe-4	RN42
ERNi-3	ERN61	ERNiCrFe-5	ERN62
RNiCu-5	RN40	ERNiCrFe-6	ERN6A
RNiCu-6	RN43	ERNiCrFe-7	ERN69
ERNiCu-7	ERN60	ERNiMo-4	ERN7B
ERNiCu-8	ERN64	ERNiMo-5	ERN7C
ERNiCr-3	ERN82	ERNiMo-6	ERN7W

Copper and copper alloy AWS A5.6-69

AWS CLASS.	MIL-E-22200/4A or MIL-E-278A	AWS CLASS.	MIL-E-22200/4A or MIL-E-278A
ECu	None		
ECuSi	None	ECuAl-B	MIL-E-278A MIL-ECuAl-B
ECuSn-A	None		
ECuSn-C	None	None	MIL-E-278A MIL-ECuAl-C
ECuNi	MIL-E-22200/4A MIL-CuNi	None	MIL-E-278A MIL-ECuAl-D
ECuAl-A1	None	None.	MIL-E-278A MIL-ECuAl-E
ECuAl-A2	None		

Mild steel AWS A5.1-69

AWS CLASS.	Military	AWS CLASS	Military
E6010	MIL-6010 MIL-G6010	E6027	MIL-6027
		E6027	MIL-6027
E6011	MIL-6011 MIL-G6011	E7014	
		E7015	MIL-7015
E6012	MIL-6012	E7016	MIL-7016
E6013	MIL-6013	E7018	MIL-7018
E6020	MIL-6020	E7024	
E6020	MIL-6020	E7028	

Brass and bronze AWS A5.7-69

Classification	Military
RCuZn-B	Mil-R-19631B Type RCuZn-B
RCuZn-C	Mil-R-19631B Type RCuZn-C

Brass and bronze AWS A5.7-69 & A5.8-69

RBCuZn-A	Mil-R-19631B Type RBCuZn-A
RBCuZn-D	Mil-R-19631B Type RBCuZn-D

Aluminum alloys AWS A5.3-69

Classification	Military
A-2	Mil-E-16053K-1, Mil-E-15597
A-43	Mil-E-16053K-1, Mil-E-15597

Aluminum alloys AWS 5.10-69

ER 1100	Mil-E-16053K-1, Mil-Std. 437
ER 4043	Mil-E-16053K-1, Mil-Std. 437
ER 5654	Mil-E-16053K-1, Mil-Std. 437

lectrode comparison tables, AWS-Military

OW-ALLOY STEEL AWS A5.5-69

AWS CLASS	Military
CARBON-MOLYBDENUM STEEL	
E7010-A1	MIL-E-15716B, MIL-7010-A1
E7011-A1	MIL-E-15716B, MIL-7011-A1
E7015-A1	–
E7016-A1	–
E7018-A1	–
E7020-A1	MIL-E-15716B, MIL-7020-A1
E7027-A1	–
CHROMIUM-MOLYBDENUM STEEL	
E8016-B1	–
E8018-B1	–
E8015-B2L	MIL-E-16589B, MIL-52-LC-15, MIL-52-LC-16
E8016-B2L	

AWS CLASS	Military
E8016-B2	MIL-E-16589B, MIL-52-16
E8018-B2	–
E9015-B3L	MIL-E-16589B, MIL-94-LC-15, MIL-94-LC-16
E9016-B3L	
E9015-B3	–
	MIL-E-16589B, MIL-94-15
E9016-B3	MIL-94-15, MIL-E-16589B, MIL-94-16
E9018-B3	–
E8015-B4L	MIL-E-16589B, MIL-[illegible]-LC-15
NICKEL STEEL	
E8016-C1	–
E8018-C1	–
E8016-C2	–
E8018-C2	–

AWS CLASS	Military
E8016-C3	MIL-E-22200/6, MIL-8016-C3, MIL-8016, MIL-E-18038A
E8018-C3	–, MIL-8018, MIL-E-22200/1C
MANGANESE-MOLYBDENUM STEEL	
E9015-D1	MIL-9015A, MIL-E-18038A
E9018-D1	–
E10015-D2	–
E10016-D2	–
E10018-D2	–
ALL OTHER LOW-ALLOY STEEL	
E9018-M	MIL-9018, MIL-E-22200/1C
E10018-M	MIL-10018, MIL-E-22200/1C

AWS CLASS	Military
E11018-M	MIL-11018, MIL-E-22200/1C
E12018-M	MIL-12018, MIL-E-22200/1C
E7010-G	–
E7011-G	–
E7015-G	MIL-7015, MIL-E-18038A, MIL-7015, MIL-E-22200/6
E7016-G	MIL-7016, MIL-E-18038A, MIL-7016, MIL-E-22200/6
E7018-G	MIL-7018, MIL-E-22200/1C
E7020-G	–
E8010-G	–
E8011-G	–

AWS CLASS	Military
E8013-G	–
E8015-G	
E8016-G	
E8018-G	
E9010-G	–
E9011-G	–
E9013-G	
E9015-G	MIL-9015, MIL-E-18038A
E9016-G	MIL-9016, MIL-E-18038A, MIL-9016A, MIL-E-18038A, MIL-94-LC-16, MIL-E-16589B, MIL-9016-CA, MIL-E-45057 (ORD)
E9018-G	
E10010-G	–
E10011-G	–
E10013-G	–

AWS CLASS	Military
E10015-G	MIL-E-22200/6, MIL-10015, MIL-230-15, MIL-E-986C
E10016-G	MIL-E-22200/6, MIL-10016, MIL-230-16, MIL-E-986C-
E10018-G	
E11015-G	
E11016-G	
E11018-G	
E12010-G	–
E12011-G	–
E12013-G	–
E12015-G	MIL-E986C, MIL-260-15
E12016-G	
E12018-G	

TAINLESS STEEL AWS A5.4-69

AWS CLASS	MIL-E-22200/2A	AWS CLASS	MIL-E-22200/2A	AWS CLASS	MIL-E-22200/2A	AWS CLASS	MIL-E-22200/2A
E308-15	MIL-308-15	E347-15	MIL-347-15	E308-16	MIL-308-16	E-347-16	MIL-347-16
E308L-15	MIL-308L-15	None	MIL-347HIC-15	E308L-16	MIL-308L-16	None	MIL-347HIC-16
None	MIL-308HIC-15	E349-15	MIL-349-15	None	MIL-308HIC-16	E349-16	MIL-349-16
E309-15	MIL-309-15	E430-15	None	E309-16	MIL-309-16	E430-16	None
E309Cb-15	MIL-309Cb-15	E7Cr-15	None	E309Cb-16	MIL-309-Cb-16	E7Cr-16	None
E309Mo-15	None		MIL-E-16589B(Ships)	E309Mo-16	None		MIL-E-16589B(Ships)
E310-15	MIL-310-15	E410-15	MIL-480-15	E310-16	MIL-310-16	E410-16	MIL-480-16
E310Cb-15	None	E505-15	MIL-365-15	E310Cb 16	None	E505-16	MIL-365-16
E310Mo-15	None	E502-15	MIL-202-15	E310Mo-16	None	E502-16	MIL-202-16
E312-15	MIL-312-15	None	MIL-202-LC-15	E312 16	MIL-312-16	None	MIL-202-LC 16
E16-8-2-15	MIL-16-8-2-15		MIL-E-13080A	E16-8-2-16	MIL 16 8 2-16		MIL-E-13080A
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E316L-15	MIL-316L-15	None	MIL-307T-15	E316L-16	MIL-316L 16	None	MIL-307T-16
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E330-15	MIL-330-15		MIL-E-22200/2A	E330-16	MIL-330 16		

The key to success lies in knowing WHERE and HOW TO APPLY your knowledge.

May we suggest that you start planning your campaign, while whatever new information you have acquired is still fresh in your mind. Jot down the names of prospects that may have occurred to you while you are attending this training session.

DO IT NOW!

PROSPECTS	SPEAK TO
1.	
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SECTION B

PREHEAT FOR WELDING

The greatest problem encountered in welding alloy steel is hardenability. When a weld bead is deposited on cold base metal, the cooling rate may change from a relatively slow air cool to a rate which is equivalent to a water quench. Cooling rates depend mainly on three variables:

1) The rate of heat input
2) Base metal temperature before welding
3) The section's mass and geometry

Therefore, the weld metal and heat affected zone may change from relatively soft and unaffected to almost fully hard, or a mixture of hard and soft structures.

In the case of multiple pass welds there is a definite and beneficial effect from the re-heating and the re-crystalization of the deposit metal by subsequent beads. Previously deposited metal and hardened base metal is reheated above the transformation temperature at least once, and to a lower, but effective, temperature possibly several times during welding. The result is comparable to a normalize and draw heat treatment. Consequently, the weld area assumes a series of graded microstructures ringing the weld zone in accordance with the temperature gradient imposed upon the metal. These structures and their orientation influence the properties of the weld area.

Pre-heating and post-heating have long been recognized as successful means of improving weld properties. It has become quite common to use a thermal stress relieving treatment, although in some instances, normalizing or full annealing is specified. In addition to producing the desired mechanical properties, the annealing and normalizing treatments have the beneficial effect of refining the grain structure in the weld zone.

The composition of the weld is a mixture of filler metal and base metal of varying proportions. Here again, metallurgy dictates what the characteristics of the heterogeneous compositon will be. The greatest single factor probably is hardenability.

RELATIVE EFFECTIVENESS OF THE COMMON ALLOYING ELEMENTS IN INCREASED HARDENABILITY*

ELEMENT	Carbon % In Amount Of: 0.20	0.30	0.40	0.50	0.60	0.80	1.00
	Ratio of Effectiveness:						
MANGANESE	1.70	2.00	2.33	2.67	3.00	3.66	4.34
MOLYBDENUM	1.60	1.90	2.20	2.50	2.80	....	....
CHROMIUM	1.43	1.65	1.87	2.08	2.30	2.73	3.15
SILICON	1.14	1.20	1.28	1.35	1.42	1.56	1.70
NICKEL	1.08	1.12	1.15	1.19	1.22	1.30	1.37

NOTE: These tables do not take into account the multiplier effect of a combination of alloying elements which tend to increase the hardenability.

* Boyd and Field.

Hardenability is defined as a property which determines the depth and distribution of hardness induced by rapid cooling of steel from an elevated temperature. Hardenability must not be confused with hardness. Hardness is defined as the resistance to an indentation. There is no close relationship between the two, despite the fact that hardness readings are commonly used to measure hardenability. Carbon is the single element that strongly influences both hardness and hardenability. The maximum hardness obtainable in plain carbon and low alloy steels is dependent almost exclusively on carbon content. Low carbon steels are readily weldable, largely because they have low hardenability and remain relatively soft and ductile after welding.

The following is reprint from "The Welding Journal" on the subject of preheat for welding:

One of the most troublesome features of the welding process is the danger of cracks developing in the weld metal or in the adjacent base metal zone.

Today's conditions serve to increase the normal risk of crack formation. One adverse factor is the pressure for increasing output in today's stepped up economy. Newly trained welders, temperamental steel compositions and various material shortages, with specifications remaining as rigid as ever, combine to make the work of the welding supervisor or engineer more troublesome than ever.

What causes cracks in welds? What factors result in conditions that favor weld cracking? What, if any, are the means of preventing cracks from occurring? In considering these questions we must remember that welding usually involves greater and more violent changes of temperature than other fabricating processes. Some of the complicated metallurgical factors involved in the welding operation are not fully understood as yet. Nevertheless, we can supply satisfactory answers to many of these questions, and the purpose of this paper is to review some of the knowledge and experience which enables us to produce satisfactory crack-free weld joints under a wide variety of conditions.

There are two areas in a welded joint which may crack as a result of the welding operation. The first is a portion of the so-called heat-affected zone adjacent to the weld. The second area which may crack under certain conditions is the weld metal itself. However, the weld metal used for most purposes has so low a carbon content that it does not change its properties as markedly as the base metal even under the most rapid rate of cooling likely to occur in welding. Therefore, the weld metal itself is less prone to cracking than the so-called heat-affected zone.

In view of this, we usually concern ourselves primarily with the base metal in the immediate vicinity of the weld. It is the metal closest to the weld that cools most rapidly, and in many cases undergoes important changes in the structure and properties that may lead to cracking.

Preheating before welding is a well-recognized preventive measure against cracking. It was used for many years before scientific reasons were advanced to explain its function in preventing cracks. The importance of preheating is shown by the fact that recommendations for preheating are written into modern welding specifications wherever there is the slightest risk of weld defect being present.

However, it is less generally recognized that preheating also contributes other useful effects. This paper will review briefly the fundamental principles involved in preheating, describe some of the beneficial effects of preheating and outline several procedures commonly used for preheating.

Preheating has been defined as "raising the temperature of metal above the temperature of the surroundings before welding." It may be added that sometimes the entire part is preheated, this being the general preheat; or, only the vicinity of the weld is heated, and this is called local preheat.

There are five principal reasons for preheating. These are listed in Table 1.

Table 1 - Effects of Preheating

1. Eliminates or lessens the danger of crack formation.
2. Minimizes hard zones adjacent to weld.
3. Minimizes shrinkage stresses.
4. Lessens distortion.
5. Enhances diffusion of hydrogen from steel.

Preheating, therefore, increases the ability of a welded joint to withstand service conditions; as will be shown below, preheating may actually be viewed as a heat-treating operation.

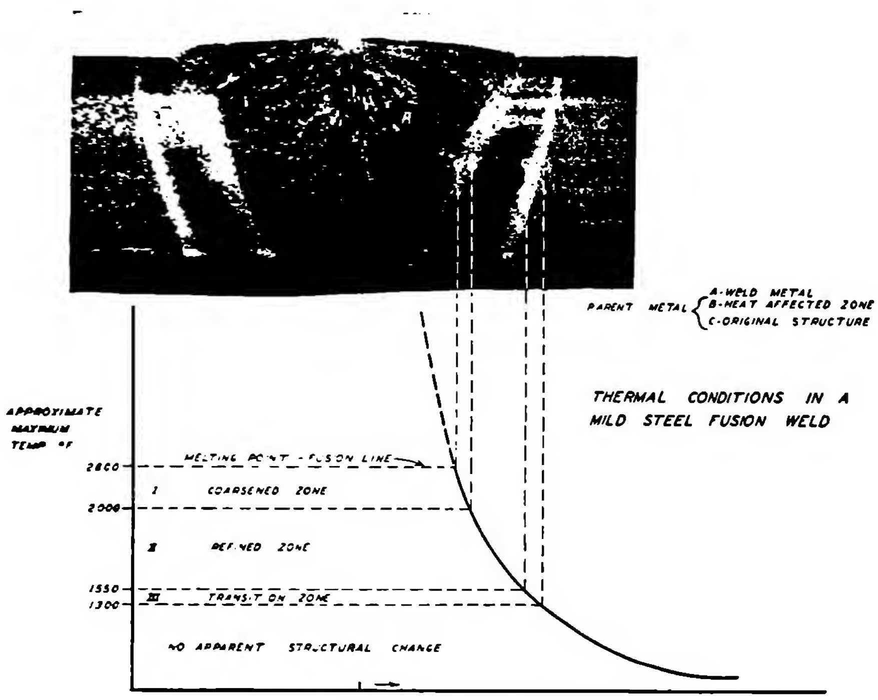
How does preheating accomplish these beneficial results? in order to answer this question it is necessary to consider several important metallurgical principles.

The making of any weld involves two metallurgical processes: First, the melting of the edges of the joint and of the electrode material, followed by solidification which forms a single integral weld structure; second, the heating and subsequent cooling of the zone of the parent metal adjacent to the weld.

The heat generated during welding will have two separate effects on the welded joint. Depending on metal composition, temperature reached and cooling rate there will be a specific effect on micro-structure of the metal, which will in turn determine such properties as strength, toughness, ductility, shock, corrosion resistance and so forth. We will call these, perhaps somewhat arbitrarily, the metallurgical effects.

Second, heat will cause distortion and shrinkage stresses in the weld joint, this being dependent on the shape and geometry of the joint, the degree of restraint, heating and cooling rates and

time at maximum temperature. We will call these the mechanical effects. Actually these two effects occur simultaneously and are interdependent, but they are separated in this discussion for convenience and simpler understanding. The welded joint, although actually a single integral structure, may be considered to consist of three distinct zones which merge into one another. The three zones are: The weld metal, the heat-affected zone and the plate material, sometimes called the base metal.



Courtesy U. S. Steel Corp. Lab.

Fig. 1—Typical macrostructures and maximum attained temperatures in a butt weld

Figure 1, which is a macrograph of a single pass butt-weld joining two plates 1 inch thick, shows these three zones. The weld metal A is that portion which has been in molten state and consists of a mixture of the electrode material which has been deposited and plate material which has been melted during welding.

The heat-affected zone, shown as B is that area which, although not melted during the welding operation, has been heated to temperatures sufficiently high to change its original microstructure and properties. This zone consists of a sequence of several distinctly different structures whose precise character and extent depend upon the conditions of welding. The plate material C is the area that has not been affected by the weld thermal cycle. The diagram below the photograph indicates the approximate maximum temperatures reached in each zone while the weld was being made. The temperatures and structures shown indicate that the thermal cycle of the welding operation subjects the metal to a heat treatment which considerably alters its structure and properties. In order to understand the nature of the changes introduced into steel by heating and cooling cycles, one must consider the iron-carbon diagram.

The iron-carbon diagram is a summary of the physical changes which occur in steels and cast irons when the temperature is varied. Figure 2 shows a portion of the iron-carbon diagram with some additional useful metallurgical and fabricating information superimposed on it.

This diagram illustrates the effects on steel structures of temperature changes that accompany the welding operation. Typical welding grade of steel, 0.25% carbon for example, if heated to a temperature above 1525°F. becomes a solid solution of carbon in iron which has a face centered crystal structure, called austenite. On slow cooling the austenite remains unchanged until the temperature of about 1500°F. is reached. At this point austenite begins to break down and form a new phase. This new phase is almost pure iron with a body centered structure and it is called ferrite. This process continues until the temperature of 1350°F. is reached. At 1350°F. the remaining austenite transforms to still another phase called pearlite. Thus on slow cooling to room temperature steel will be composed of a ferrite-pearlite structure. This structure is soft and ductile. However, the cooling rates in welds are as a rule not slow but quite rapid. Drastic cooling of steel results in formation of a hard and brittle structure called martensite. Thus, instead of soft and ductile pearlite we get hard martensite, which due to its low ductility has poor ability to withstand welding stresses. It is the formation of this brittle structure in the base metal that causes much weld cracking.

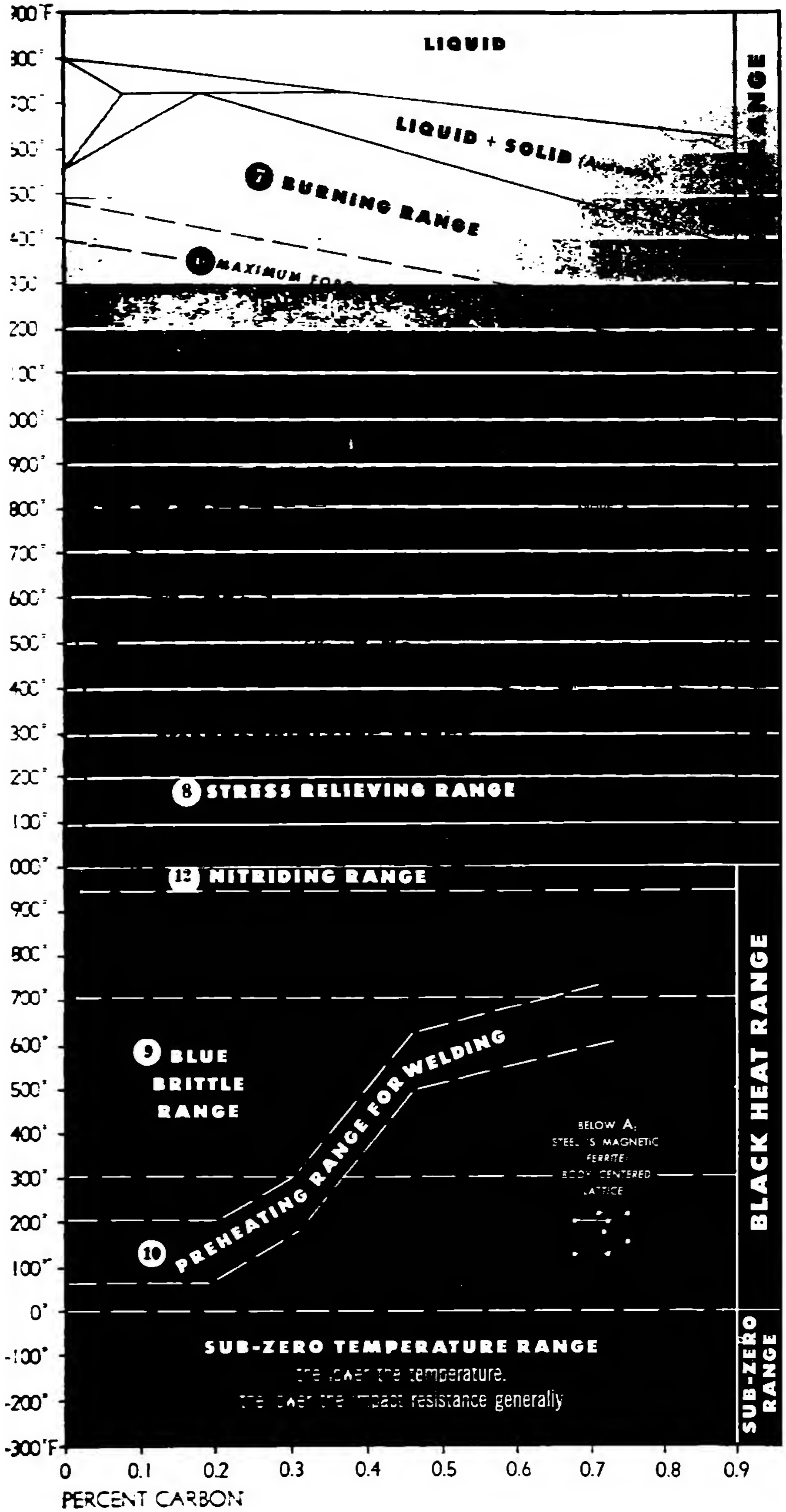
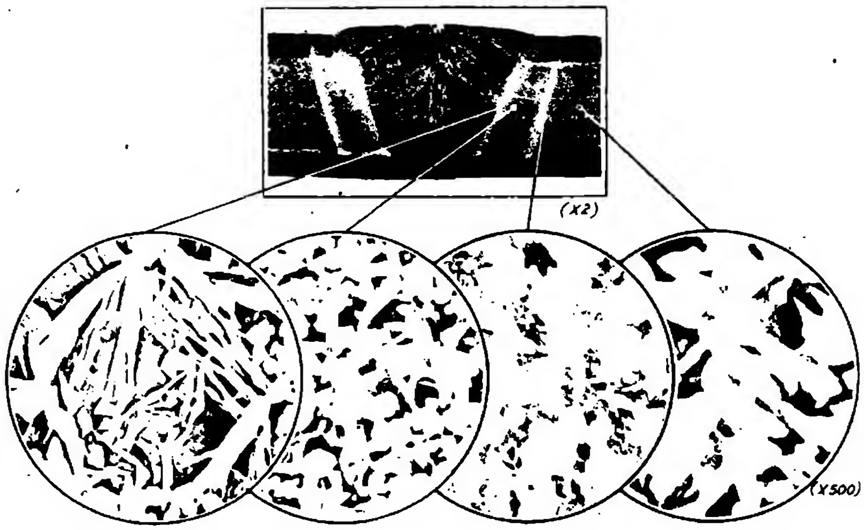

LIQUID
LIQUID + SOLID
7 BURNING RANGE
8 STRESS RELIEVING RANGE
12 NITRIDING RANGE
9 BLUE BRITTLE RANGE
10 PREHEATING RANGE FOR WELDING
BELOW A1
BLACK HEAT RANGE
SUB-ZERO TEMPERATURE RANGE
SUB-ZERO RANGE
900°
800°
700°
600°
500°
400°
300°
200°
100°
0°
-100°
-200°
-300°F
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PERCENT CARBON

Fig. 2

This metallurgical knowledge helps to interpret some of the typical structures that may be found in the heat-affected zones of a welded joint. These are shown in Figure 3.



Courtesy U. S. Steel Corp. Lab.

Fig. 3—Typical microstructures in the heat-affected zone of a butt weld

It is apparent that Zone 1 has been coarsened by the welding process and consists of a needlelike martensitic structure; Zone 2 has been refined by the heat incident to the welding operation and Zone 3 is a transition zone. Figure 3 also shows the typical normalized structure of the original unaffected parent metal.

The principal danger of cracking is found in Zone 1 which consists principally of coarsened martensite. Figure 4 shows this structure under higher magnification. The brittle martensite present gave rise to a crack which in all probability, will eventually extend further under the influence of welding stresses.

Courtesy Lehigh University

Fig. 4—Initial crack in hardened portion of the heat affected zone of the weld

The factors just described comprise the metallurgical effects of the welding operation. The mechanical effects of the heating and cooling cycles during welding result in sudden and highly nonuniform expansion and contraction. These will set up stresses that cause the welded joint to deform continually during and after the welding cycle. In general a metal will crack if stresses exceed its ability to deform. Thus a weld joint composed of a material which possesses sufficient ductility --- such as ferrite and pearlite --- will deform without cracking while a weld which contains a brittle structure such as martensite may react to thermal stresses by cracking. This illustrates the interdependence of metallurgical and mechanical considerations stated previously.

With this background, the five factors which determine the ability of steel to be welded without cracking can be listed as follows:

Table 2

1. Composition of steel.
2. Rate of heating.
3. Maximum temperature attained and length of time at temperature.
4. Rate of cooling.
5. Hydrogen entrapment.

The chemical composition of steel has a very important bearing on the hardness and brittleness of the weld joint for several reasons: First, because higher carbon content promotes the formation of martensite, and second, because the final hardness or martensite itself depends on the carbon content of steel. The effect of carbon content on hardness of steel subjected to welding is shown in Figure 5.

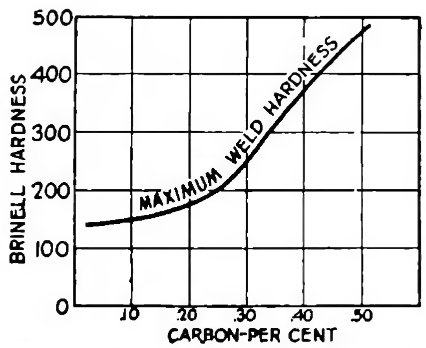


Fig. 5 Effect of carbon content in plain carbon steels after weld hardening procedure

This, of course, is the reason why steels of higher carbon analysis are not considered easily weldable. Certain alloying elements such as molybdenum, manganese, vanadium and chromium also have a distinct hardening effect, promoting the formation of the crack-inducing martensite. The relative hardening influence of the important alloying elements is indicated in Figure 6. Thus the higher the carbon and alloy content of steel the more readily it will harden in the heated zone, and therefore the slower the cooling rate will have to be in order to prevent cracking.

The next three factors in Table 2 are of thermal nature. The great and violent changes in temperature involved in welding can be illustrated by temperature changes of a point in the heat-affected zone of a weld. Such a typical time-temperature curve is shown in Figure 7. Within the first second after welding this point rapidly reaches a very high temperature of approximately

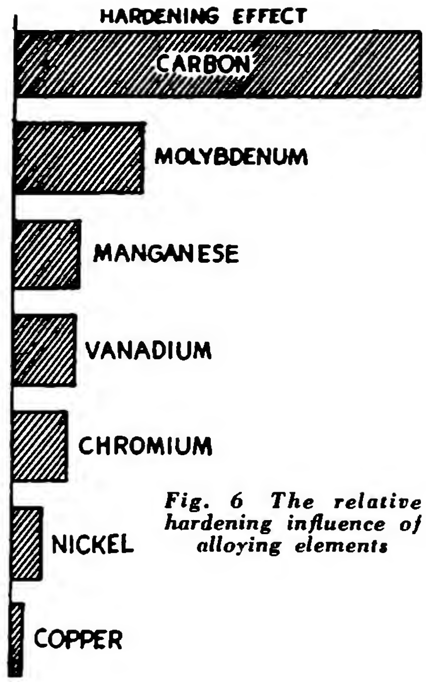


Fig. 6 The relative hardening influence of alloying elements

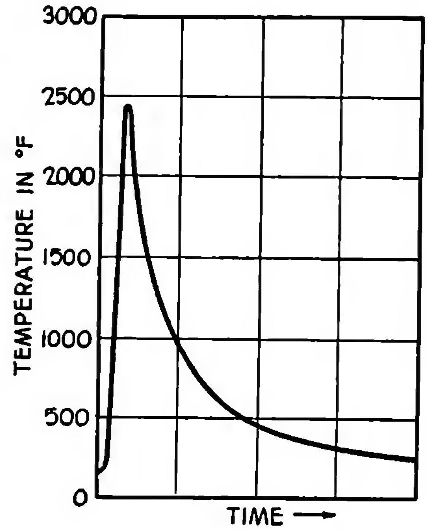


Fig. 7 Typical time-temperature curve for a point in the heat-affected zone of a weld

2450°F., and then drops in the next few seconds to temperatures below 500°F.

The rate of heating is important for two reasons. First, because rapid heating may result in high thermal stresses, and second, because rapid heating will cause a high cooling rate thus promoting the formation of brittle martensite. The rate of heating will determine the steepness of the rising portion of the curve in Figure 7 and it will vary with the welding process or, more specifically with the method used for generating heat at weld joint---electric arc, oxyacetylene, heliarc and so on. For example, the electric arc provides a faster rate of heating than the oxyacetylene because the arc is a more intense heat source, and is in more intimate contact with the metal. The maximum temperature and the time at temperature are important because they determine the amount of austenite that will be formed and thus the amount of change in microstructure which will take place.

The maximum temperature attained and the time at temperature besides being influenced by the welding process employed are also dependent on other factors such as the time and speed of welding, arc current, arc voltage and the welding sequence. In other words, the maximum temperature reached depends upon the heat input of a welding rod. A 1/4 inch diameter electrode used at 400 amp. and 40 v. will result in higher maximum temperature of a joint in the heat-affected zone than a 1/8 inch electrode used with 150 amp. and 20 v. A higher temperature will also be obtained at any location in the heat-affected zone if the speed of travel were 6 inches per minute instead of 12 inches per minute, other factors being equal. The use of string bead or weave technique, the number of layers and the time between succeeding weld beads all play an important part in determing the maximum temperature attained.

Of the five factors in Table 2, the rate of cooling has the greatest influence on the structures of the heat-affected zone. As shown previously the cooling rate will determine the final structures of the transformation products which result from the welding operation. If austenite is cooled slowly the transformation products will be soft and ductile. If the transformation from austenite is rapid, the final products will be brittle and may crack if stressed. As welding is a quick process, the cooling rates are quite rapid and the portions of the heat-affected zone are likely to consist of this brittle constituent. Thus the cooling rate determines the hardness and brittleness in the heat-affected zone and by controlling the cooling rate it is possible to create welding conditions which will prevent this brittle structure from forming, and thus prevent cracks. The rate of cooling is dependent on the mass and geometry of the piece to be welded, the temperature gradient between the weld joint and the base metal and the total heat input.

Some authorities believe that cracks in welds are due to hydrogen introduced into the base metal from the coatings of welding rods. As hydrogen is more soluble in molten than in solid steel, it will seek to escape from the supersaturated solution as metal cools down to room temperature. If the escaping hydrogen is trapped within a discontinuity in the metal, and if such entrapment occurs within a hardened area, cracking may result.

Two practices are commonly utilized to prevent the formation of cracks in welded joints: Preheating and postheating. Preheating is used to prevent cracks during and immediately after the welding operation, and postheating to insure crack-free welds before the metal enters service and also to insure satisfactory metallurgical properties to withstand service conditions. Preheating acts to prevent cracks in several ways. First, it reduces the thermal gradient between base and weld metals. For example, a drop of only 2000°F. occurs if a weld is preheated to 800°F. as compared with the 2730° drop from 2800° to 70°F. for a weld made at room temperature. This reduces the cooling rate preventing the formation of brittle martensite and causing metallurgical transformations to take place that produce softer and more ductile constituents. Thus preheating reduces the hardness of the heat-affected zone and the tendency to cracking.

As steel is less heat conductive at higher temperatures, preheating causes slower withdrawal of heat from the welded joint. This further lowers the cooling rate with correspondingly beneficial effects.

Preheating has been found to be helpful in eliminating hydrogen entrapment in the base material. Many fabricating procedures recommend preheating even in conjunction with the low-hydrogen type electrodes. Although the arc atmospheres of the so-called hydrogen-free electrodes contain very small amounts of hydrogen---even traces of this element are sometimes sufficient to cause cracking in the embrittled heat-affected zone.

The useful effects of preheating can be summarized as follows: Hard martensitic zones occur in weld joints as a result of rapid cooling rates. These hard zones are likely to crack during or after the welding operation. The shrinkage stresses due to cooling augmented by the volume changes of steel during phase transitions may exceed the capacity of the hard zone to deform and thereby crack it. This may be aided by the presence of hydrogen which has an embrittling effect on steel. Preheating prevents weld cracking in three ways: It minimizes the formation of the brittle martensite, it causes austenite to transform very slowly to martensite and it increases the diffusion and escape rate of hydrogen.

The foregoing is summarized in practical terms in Table 3 as the eleven factors which increase the need for preheating.

Table 3

Preheating Need Is Increased If the Welded Piece

1. Has larger mass.
2. Is at lower temperature.
3. Is in an environment of lower temperature.
4. Is welded with smaller rod diameter.
5. Is welded at greater linear speed.
6. Has complicated shape and design.
7. Has large variation in size of adjacent parts.
8. Has higher carbon content.
9. Has higher manganese content.
10. Has higher alloy content.
11. Has greater air-hardening capacity.

A chart which summarizes recommended preheat temperatures for 79 commonly used metal and alloys is shown in Table 4.

Preheating is usually accomplished by various methods. The most popular ones involves the use of gas torches, various other types of burners, regular heat-treating furnaces, electrical strip heaters, low-frequency induction heating and firebrick furnaces utilizing charcoal or coke as fuel. The choice of a particular method depends, of course, on many factors such as the preheating temperature and length of preheating time required, size and shape of piece being welded, whether production is of a batch or continuous type and so forth. A typical firebrick furnace construction which utilizes charcoal or coke as fuel is shown in Figure 8. This type of furnace is popular for temporary work as it can be readily erected and, if necessary, easily dismantled. In many shops regular heat-treating furnaces, such as shown in Figure 9, are utilized for preheating. These are particularly advantageous in mass production work, and are sometimes combined with the other methods of preheating in order to save labor and fuel. For example, the castings preheated in continuous annealing furnaces shown in Figure 9 are removed to the casting repair area where specially shaped multiple jet heating torches (Figure 10) are used to maintain preheat temperatures attained in furnaces.

Courtesy Air Reduction Sales Co.

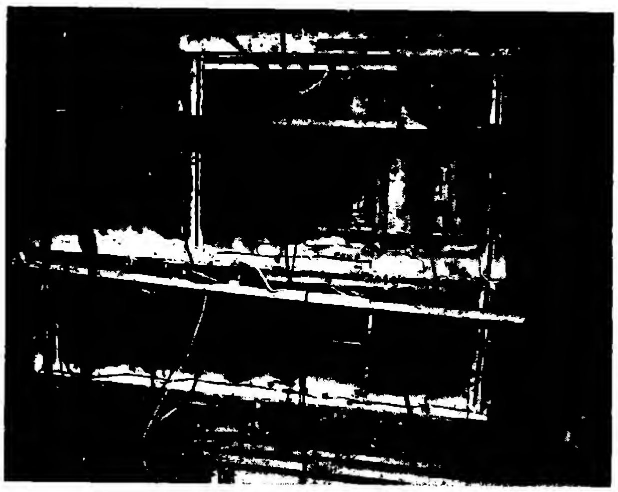
Fig. 8 Temporary firebrick charcoal fired furnace for preheat of castings

Fig. 9 Continuous annealing furnaces used for preheat of castings

Courtesy "The Welding Engineer"

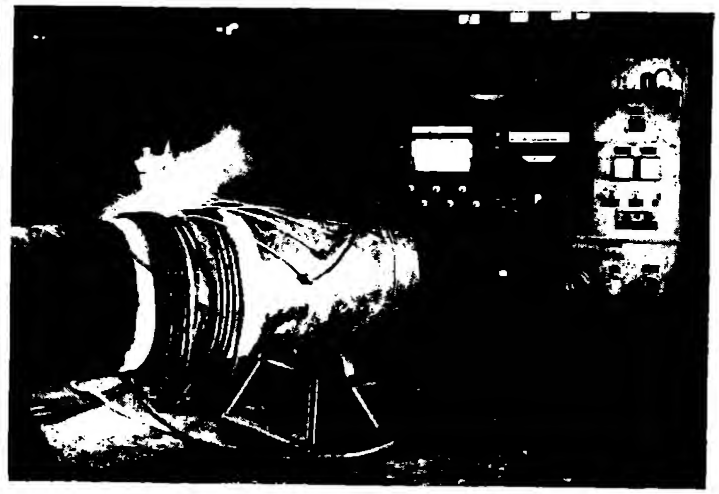
Fig. 10 Preheat imparted by continuous furnaces is maintained by means of gas torches and asbestos blankets

In heavy fabrication like shipbuilding and the manufacture of large pressure vessels which require continuous application of preheat, a popular method utilizes electrical strip heaters, shown in Figure 11.



Courtesy the Newport News Shipbuilding & Dry Dock Co.

***Fig. 11* Electrical strip heaters in place on a typical shell repair**



Courtesy "The Welding Engineer"

***Fig. 12* Preheating by induction during welding**

Another widely employed method utilizes low-frequency induction heating and is particularly useful where close temperature control is required. Figure 12 shows the use of induction heating in preheating of alloy steel piping prior to welding.

Preheating before welding is now widely accepted as a desirable fabricating procedure. Both ferrous and nonferrous metal producers state recommended preheating temperatures for welding their materials. Prescribed preheating temperatures and procedures are today included in the majority of fabricating specifications. While preheating methods and temperatures will depend on many factors like metal composition and mass, fabricating methods and service conditions, there is unanimous agreement that preheating before welding is the best possible insurance against cracks.

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TEMPIL° PREHEATING CHART

METAL GROUP	METAL DESIGNATION	APPROXIMATE COMPOSITION — PERCENT C.	Mn.	Si.	Cr.	Ni.	Mo.	Cu.		METAL DESIGNATION	RECOMMENDED PREHEAT	USE THESE TEMPILSTIKS
PLAIN CARBON STEELS	PLAIN CARBON STEEL	BELOW .20								PLAIN CARBON STEEL	UP TO 200°F	200
	PLAIN CARBON STEEL	.20-.30								PLAIN CARBON STEEL	200°F-300°F	200-300-400
	PLAIN CARBON STEEL	.30-.45								PLAIN CARBON STEEL	300°F-500°F	300-400-500
	PLAIN CARBON STEEL	.45-.80								PLAIN CARBON STEEL	500°F-800°F	500-600-700-800
CARBON MOLY STEELS	CARBON MOLY STEEL	.10-.20					.50			CARBON MOLY STEEL	300°F-500°F	300-400-500
	CARBON MOLY STEEL	.20-.30					.50			CARBON MOLY STEEL	400°F-600°F	400-500-600
	CARBON MOLY STEEL	.30-.35					.50			CARBON MOLY STEEL	500°F-800°F	500-600-700-800
MANGANESE STEELS	SILICON STRUCTURAL STEEL	.35	.80	.25						SILICON STRUCTURAL STEEL	300°F-500°F	300-400-500
	MEDIUM MANGANESE STEEL	.20-.25	1.0-1.75							MEDIUM MANGANESE STEEL	300°F-500°F	300-400-500
	SAE T 1330 STEEL	.30	1.75							SAE T 1330 STEEL	400°F-600°F	400-500-600
	SAE T 1340 STEEL	.40	1.75							SAE T 1340 STEEL	500°F-800°F	500-600-700-800
	SAE T 1350 STEEL	.50	1.75							SAE T 1350 STEEL	600°F-900°F	600-700-800-900
	12% MANGANESE STEEL	1.25	12.0							12% MANGANESE STEEL	USUALLY NOT REQUIRED	
HIGH TENSILE STEELS (SEE ALSO STEELS BELOW)	MANGANESE MOLY STEEL	.20	1.65	.20			.35			MANGANESE MOLY STEEL	300°F-500°F	300-400-500
	JALTEN STEEL	.35 MAX.	1.50	.30				.40		JALTEN STEEL	400°F-600°F	400-500-600
	MANTEN STEEL	.30 MAX.	1.35	.30				.20		MANTEN STEEL	400°F-600°F	400-500-600
	ARMCO HIGH TENSILE STEEL	.12 MAX				.50 MIN.	.05 MIN.	.35 MIN.		ARMCO HIGH TENSILE STEEL	UP TO 200°F	200
	DOUBLE STRENGTH #1 STEEL	.12 MAX.	.75			.50-1.25	.10 MIN.	.50-1.50		DOUBLE STRENGTH #1 STEEL	300°F-600°F	300-400-500-600
	DOUBLE STRENGTH #1A STEEL	.30 MAX.	.75			.50-1.25	.10 MIN.	.50-1.50		DOUBLE STRENGTH #1A STEEL	400°F-700°F	400-500-600-700
	MAYARI R STEEL	.12 MAX.	.75	.35	.2-1.0	.25-.75		.60		MAYARI R STEEL	UP TO 300°F	200-300
	OTISCOLOY STEEL	.12 MAX.	1.25	.10 MAX.	.10 MAX.			.50 MAX.		OTISCOLOY STEEL	200°F-400°F	200-300-400
	NAX HIGH TENSILE STEEL	.15-.25		.75	.60	.17	.15 MAX.	.25 MAX.	Zr. .12	NAX HIGH TENSILE STEEL	UP TO 300°F	200-300
	CROMANSIL STEEL	.14 MAX.	1.25	.75	.50					CROMANSIL STEEL	300°F-400°F	300-400
	A. W. DYN-EL STEEL	.11-.14						.40		A. W. DYN-EL STEEL	UP TO 300°F	200-300
	CORTEN STEEL	.12 MAX.		.25-1.0	.5-1.5	.55 MAX.		.40		CORTEN STEEL	200°F-400°F	200-300-400
	CHROME COPPER NICKEL STEEL	.12 MAX.	.75		.75	.75		.55		CHROME COPPER NICKEL STEEL	200°F-400°F	200-300-400
	CHROME MANGANESE STEEL	.40	.90		.40					CHROME MANGANESE STEEL	400°F-600°F	400-500-600
	YOLOY STEEL	.05-.35	.3-1.0			1.75		1.0		YOLOY STEEL	200°F-600°F	200-300-400-500-600
	HI-STEEL	.12 MAX.	.6	.3 MAX.		.55		.9-1.25		HI-STEEL	200°F-500°F	200-300-400-500
NICKEL STEELS	SAE 2015 STEEL	.10-.20				.50				SAE 2015 STEEL	UP TO 300°F	200-300
	SAE 2115 STEEL	.10-.20				1.50				SAE 2115 STEEL	200°F-300°F	200-300
	2½% NICKEL STEEL	.10-.20				2.50				2½% NICKEL STEEL	200°F-400°F	200-300-400
	SAE 2315 STEEL	.15				3.50				SAE 2315 STEEL	200°F-500°F	200-300-400-500
	SAE 2320 STEEL	.20				3.50				SAE 2320 STEEL	200°F-500°F	200-300-400-500
	SAE 2330 STEEL	.30				3.50				SAE 2330 STEEL	300°F-600°F	300-400-500-600
	SAE 2340 STEEL	.40				3.50				SAE 2340 STEEL	400°F-700°F	400-500-600-700
MEDIUM NICKEL CHROMIUM STEELS	SAE 3115 STEEL	.15			.60	1.25				SAE 3115 STEEL	200°F-400°F	200-300-400
	SAE 3125 STEEL	.25			.60	1.25				SAE 3125 STEEL	300°F-500°F	300-400-500
	SAE 3130 STEEL	.30			.60	1.25				SAE 3130 STEEL	400°F-700°F	400-500-600-700
	SAE 3140 STEEL	.40			.60	1.25				SAE 3140 STEEL	500°F-800°F	500-600-700-800
	SAE 3150 STEEL	.50			.60	1.25				SAE 3150 STEEL	600°F-900°F	600-700-800-900
	SAE 3215 STEEL	.15			1.00	1.75				SAE 3215 STEEL	300°F-500°F	300-400-500
	SAE 3230 STEEL	.30			1.00	1.75				SAE 3230 STEEL	500°F-700°F	500-600-700
	SAE 3240 STEEL	.40			1.00	1.75				SAE 3240 STEEL	700°F-1000°F	700-800-900-1000
	SAE 3250 STEEL	.50			1.00	1.75				SAE 3250 STEEL	900°F-1100°F	900-1000-1100
	SAE 3315 STEEL	.15			1.50	3.50				SAE 3315 STEEL	500°F-700°F	500-600-700
	SAE 3325 STEEL	.25			1.50	3.50				SAE 3325 STEEL	900°F-1100°F	900-1000-1100
	SAE 3435 STEEL	.35			.75	3.00				SAE 3435 STEEL	900°F-1100°F	900-1000-1100
	SAE 3450 STEEL	.50			.75	3.00				SAE 3450 STEEL	900°F-1100°F	900-1000-1100
MOLY BEARING CHROMIUM AND CHROMIUM NICKEL STEELS	SAE 4140 STEEL	.40			.95		.20			SAE 4140 STEEL	600°F-800°F	600-700-800
	SAE 4340 STEEL	.40			.65	1.75	.35			SAE 4340 STEEL	700°F-900°F	700-800-900
	SAE 4615 STEEL	.15				1.80	.25			SAE 4615 STEEL	400°F-600°F	400-500-600
	SAE 4630 STEEL	.30				1.80	.25			SAE 4630 STEEL	500°F-700°F	500-600-700
	SAE 4640 STEEL	.40				1.80	.25			SAE 4640 STEEL	600°F-800°F	600-700-800
	SAE 4820 STEEL	.20				3.50	.25			SAE 4820 STEEL	600°F-800°F	600-700-800
LOW CHROME MOLY STEELS	2% Cr.-½% Mo. STEEL	UP TO .15			2.0		0.5			2% Cr.-½% Mo. STEEL	400°F-600°F	400-500-600
	2% Cr.-½% Mo. STEEL	.15-.25			2.0		0.5			2% Cr.-½% Mo. STEEL	500°F-800°F	500-600-700-800
	2% Cr.-1% Mo. STEEL	UP TO .15			2.0		1.0			2% Cr. 1% Mo. STEEL	500°F-700°F	500-600-700
	2% Cr.-1% Mo. STEEL	.15-.25			2.0		1.0			2% Cr. 1% Mo. STEEL	600°F-800°F	600-700-800
MEDIUM CHROME MOLY STEELS	5% Cr.-½% Mo. STEEL	UP TO .15			5.0		0.5			5% Cr.-½% Mo. STEEL	500°F-800°F	500-600-700-800
	5% Cr.-½% Mo. STEEL	.15-.25			5.0		0.5			5% Cr.-½% Mo. STEEL	600°F-900°F	600-700-800-900
	8% Cr.-1% Mo. STEEL	.15 MAX.			8.0		1.0			8% Cr.-1% Mo. STEEL	600°F-900°F	600-700-800-900
PLAIN HIGH CHROMIUM STEELS	12-14% Cr. TYPE 410	.10			13.0					12-14% Cr. TYPE 410	300°F-500°F	300-400-500
	16-18% Cr. TYPE 430	.10			17.0					16-18% Cr. TYPE 430	300°F-500°F	300-400-500
	23-30% Cr. TYPE 446	.10			26.0					23-30% Cr. TYPE 446	300°F-500°F	300-400-500
HIGH CHROME NICKEL STAINLESS STEELS	18% Cr. 8% Ni. TYPE 304	.07			18.0	8.0				18% Cr. 8% Ni. TYPE 304	USUALLY DO NOT REQUIRE PREHEAT BUT IT MAY BE DESIRABLE TO REMOVE CHILL	200
	25-12 TYPE 309	.07			25.0	12.0				25-12 TYPE 309		
	25-20 TYPE 310	.10			25.0	20.0				25-20 TYPE 310		
	18-8 Cb. TYPE 347	.07			18.0	8.0			Cb. 10XC	18-8 Cb. TYPE 347		
	18-8 Mo. TYPE 316	.07			18.0	8.0	2.5			18-8 Mo. TYPE 316		
	18-8 Mo. TYPE 317	.07			18.0	8.0	3.5			18-8 Mo. TYPE 317		
IRONS	CAST IRON									CAST IRON	700°F-900°F	700-800-900
	Ni RESIST									Ni RESIST	500°F-1000°F	500-700-900-1000
NON FERROUS	ALUMINUM									ALUMINUM	500°F-700°F	500-600-700
	MONEL									MONEL	200°F-300°F	200-300
	NICKEL									NICKEL	200°F-300°F	200-300
	INCONEL									INCONEL	200°F-300°F	200-300
	COPPER									COPPER	500°F-800°F	500-600-700-800
	ZINC									ZINC	200°F-300°F	200-300

PREHEATING PRIOR TO WELDING WILL

1. Eliminate the danger of formation of cracks.
2. Reduce Hardness.
3. Reduce Distortion.
4. Reduce or prevent Shrinkage Stresses.

THE NEED FOR PREHEATING INCREASES AS THE FOLLOWING FACTORS ARE CHANGED

1. The larger the mass being welded.
2. The lower the temperature of the pieces being welded.
3. The lower the atmospheric temperature.
4. The smaller the weld rod in diameter.
5. The greater the speed of welding.
6. The higher the Carbon content of the steel.
7. The higher the Manganese content.
8. The greater the Alloy content in air hardening steels.
9. The more the air hardening capacity of the steel.
10. The greater the difference in mass between the two pieces being joined.
11. The more complicated the shape or section of the parts.

TEMPILSTIKS ARE ALSO RECOMMENDED FOR INDICATING TEMPERATURES IN —

SURFACE WELDING

HARD FACING

OVERLAYING FOR CORROSION RESISTANCE

TORCH OR FLAME CUTTING

FLAME CONDITIONING OF SEMI-FINISHED STEEL

HEAT TREATMENT

LOCAL HEATING AND COOLING

PIPE BENDING

SHEARING OF BAR STEEL

STRAIGHTENING HARDENED PARTS

SHRINKING ONE PART ON ANOTHER

RECONDITIONING REFINERY STILL TUBES

REPAIR WELDING COSTLY DIES

TARRING CAST IRON MOULDS

TARRING CAST IRON PIPE

STACK TEMPERATURES

BRAZING

SOLDERING

FABRICATION OF NON FERROUS METALS

PRINTED IN U.S.A.

POST WELD TREATMENT PROCEDURES

DEFINITE TIME - TEMPERATURE CYCLE

1) Heating
2) Holding at temperature (soaking), and
3) Cooling

A) STRESS RELIEVING

Used with high carbon, medium carbon and alloy steels or heavy weldments of low carbon steels.

PRIMARY PURPOSE

Relieve stresses put into weldment by welding.

TEMPERATURE

Procedure - uniform heating to a temperature sufficient to relieve the major portion of these stresses - also used to relieve stresses caused by machining or cold working. Temperature always below the critical range of base metal.

TIME

And followed by uniform cooling.

B) ANNEALING

Used to soften steel so that it can be more readily machined and cold worked, to refine the grain structure and remove stresses.

TEMPERATURE

Steel heated to about 100°F. above transformation or critical range and held there long enough for carbon to distribute itself uniformily throughout the matrix.

TIME HELD SOAKING

Depends upon thickness usually one (1) hour per inch of thickness.

B) <u>TIME COOLED</u>

Slow cooling - slack lime ashes - insulating material.

C) <u>NORMALIZING</u>

Faster than annealing, not so severe a structural change.

<u>TEMPERATURE HEATING</u>

To 100°F. above transformation range - held there.

<u>TIME</u>

Briefly - than cooled in air.
Refines grains.
Relieves stresses and refines grains but does not radically change weld metal properties.

SECTION C

LOW HYDROGEN ELECTRODES

To say that a bead of deposited weld metal contains hydrogen gas seems fantastic. Nevertheless, that is as true as can be.

Engineers eventually became aware of this fact and began studying the effects of this gas on the weld. It was in the course of these studies that it became apparent that much of the cracking of welds---especially under bead cracking---is caused by hydrogen in the weld.

These studies gained considerable momentum during the war, particularly under the guidance of J. H. Humberstone who was then associated with the Electrode Research and Development Program of the National Research Council.

The fact that hydrogen was actually entrapped in the weld was confirmed by the simple experiment of immersing a specimen containing a weld bead in a tube of glycerin and observing the gas escape. The specimen of E6010 weld metal became very active in emitting hydrogen almost at once (Figure 1) and continued to emit gas for about 120 hours. A specimen of "low hydrogen" weld did not become active for about 30 minutes and was completely clear of all escaping gas in about 24 hours. The gas given off was analyzed and was found to be hydrogen.

It is believed that in welding, the hydrogen initially becomes trapped in localized zones or pockets of the weld metal and adjacent base metal. These pockets may be very small and the pressure high enough to initiate minute cracks. As further cooling takes place these cracks may increase in size but do not necessarily become visible on the surface or even under x-ray examination. Some time after welding (hours, days, months or even years) as the parts are handled and submitted to use, the cracks grow still further until they become visible on the exterior, and cause failure.

Extensive testing has shown the incidence of this cracking is directly related to the amount of hydrogen present in the weld metal. Further that the amount of hydrogen is related to the chemicals used in the electrode coatings. Therefore---it was reasoned---any means which would reduce the hydrogen would prove helpful in minimizing or eliminating the cracking. It was known that preheating and postheating (stress relieving) would accelerate the evolution of hydrogen from the metal, and were known to be helpful. However, their use is costly and not always practicable.

Following these studies Airco and other companies developed a 60,000 psi tensil electrode which used a type of coating giving a deposit almost entirely free of hydrogen. Thus was born the so-called "low hydrogen" type electrode.

The first electrode of this type introduced by us was Airco 312. Originally Airco 312 belonged to the E6015 classification suitable for DC use only. Later, however, 312 was changed to work both on AC and DC and thus was converted to the E6016 type and is now classed as E7016. Later still, we developed Airco 394, another "low hydrogen" electrode, but belonging to the E10016 class and having a much greater tensile strength than Airco E7016.

Since then, the general "low hydrogen" formula has been applied with notable success to a number of other Airco electrodes, so that today the Airco line of "low hydrogen" electrodes includes no less than 24 different types ranging from E70XX to E120XX.

The common characteristic of these 24 types of electrodes is that all of them employ coating materials of low hydrogen content, which produce weldments virtually free of hydrogen. The tests illustrated in Figures 1 and 2, actually provide a comparison in this respect between type E6010, E6012 and E6020 electrodes, and Airco E7016 which was used in producing the sample marked, "Special" in the illustrations.

Figure 1 - Samples of weld metal from an E6010 electrode (left) and from an Airco "low Hydrogen" electrode (right) show the amount of hydrogen gas emitted by the weld metal after two minutes of emersion in glycerin. Note the E6010 is completely active whereas the "low hydrogen" shows nothing.

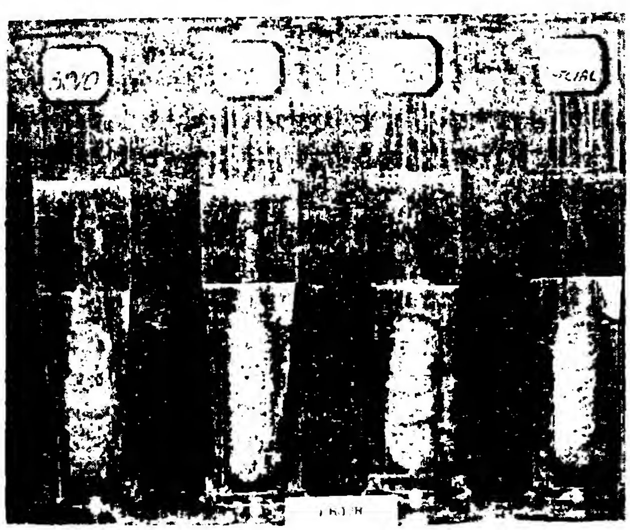

Figure 2 - After one hour immersion note that the E6010 weld metal is very active in emitting hydrogen. The hydrogen bubbles from the Airco "low Hydrogen" electrode have reached their maximum peak, which you will note is very low.

ADVANTAGES OF LOW HYDROGEN ELECTRODES

The main advantage of "low hydrogen" electrodes can be summed up in the statement that---THEY MAKE POSSIBLE THE WELDING OF CERTAIN METALS WHICH PREVIOUSLY COULD NOT BE WELDED, EXCEPT WITH VERY POOR RESULTS OR AT CONSIDERABLE EXPENSE.

Two other important advantages, however, must also be mentioned:

1. Regardless of what metal they are used on, "low hydrogen" electrodes produce stronger and more dependable welds, which are less susceptible to cracking in the beads.

2. Even without benefit of stress relief, the weld deposit of "low hydrogen" electrodes is far more resistant to shock than the weld metal of standard electrodes that have been submitted to stress relieving.

This has been demonstrated by explosive tests carried out by the Navy wherein they detonated a powder charge over a steel plate. The plate welded with the conventional type mild steel electrodes (E6010) failed at approximately half the powder charge needed to produce failure in an unwelded plate. When a mild steel "low hydrogen" type electrode was substitutes, the resistance to the explosive tests was increased to about 85% of the parent plate. These tests were made on ordinary mild steel ship plate and demonstrated the superior resistance to shock even where steel of low hardenability is involved.

APPLICATIONS

The advantages offered by "low hydrogen" electrodes will be seen more clearly as we examine the specific applications which call for the use of this type of electrode.

1. <u>Welding on Hardenable Steels</u> -- The cracking tendency mentioned earlier in the article is especially pronounced in hardenable steels---i.e., steels which increase in hardness when heated to welding temperature and then cooled rapidly by the surrounding air and mass of adjacent, relatively cold metal.

Therefore, one of the major applications for "low hydrogen" electrodes is in the welding of hardenable steels which possess strong cracking tendencies when welded with conventional electrodes.

2. <u>Welding on Cold Rolled and High Sulphur, Free Machining Steels</u> -- Arc welding of cold rolled or high sulphur, free machining steels (SAE 1100 and 1300 series) has always presented problems. Conventional electrodes produce porous welds which are unsuited for most uses, unless they are subjected to extensive machining. Such steels may be welded with complete success using the Airco E7016 "low hydrogen" type electrode. Figure 3 shows a section of round free machining screw stock welded to cold rolled mild steel bar stock. You will note the scattered surface holes that are present in the deposit from the E6010 electrode and the complete absence of holes in the deposit from the "low hydrogen" type. These holes are caused by hydrogen sulphide formed by the sulphur in the steel combining with hydrogen.

Thus steels of the SAE 1100 and 1300 series which not so long ago were considered unsuitable for welded fabrication---except at considerable expense---can now be easily welded and machined because of the availability of "low hydrogen" electrodes.

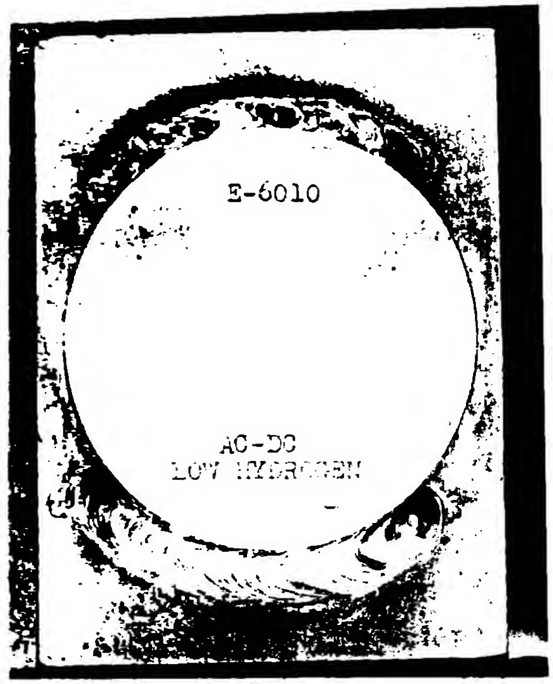

Figure 3 - Contrast the porosity of
with a standard electrode with the s
weld of an Airco 312.

3. Work Where the Type of Steel Used is
peculiar advantages possessed by "low
electrodes strongly recommend their u
type of steel to be welded is not kno
tion frequently occurs in job welding
maintenance shops of large plants. T
Airco E7018 in such instances represe
insurance of a first-class welding jo
eliminates the possibility of weld fa
use of steel of special analysis.

4. Welding Prior to Vitreous Enameling --
is applied to steel for many purposes-
make vessels used in the chemical and
corrosion resistant....in the manufact
sinks and a multitude of other househo
in the manufacture of architectural pa
details for buildings, etc.

In the past it has always been necessary to stress relieve arc welded units which were to be enameled. If stress relieving was not employed, then the enamel coating would flake or "fish scale" in the region of the weld. Such failures have been attributed to the presence of hydrogen in the weld metal.

In any case, the use of Airco E7018 electrodes when welding units which will be subjected to vitreous enameling permits dispensing entirely with stress relieving and at the same time, ensures adherence of enamel to steel.

5. Work Requiring the Most Dependable Welds -- As has been pointed out already, "low hydrogen" electrodes produce the highest quality weld deposits and are generally selected where service conditions are severe.

   In jobs such as attaching cams and other machine elements to cold rolled shafting or the welding of high carbon rails to mild steel structures, "low hydrogen" electrodes should usually be recommended.

6. Work Which is Subjected to Severe Shock -- The best examples of this are armor plate weldments. In this field the Armed Forces have found that "low hydrogen" type electrodes produce the best results.

MARKETS

Although it will be obvious that stove manufacturers and other manufacturers of products made of enamel-on-steel represent distinct and excellent outlets by and large the market for "low hydrogen" electrodes is created by the application or the type of steel used and is not confined to any particular group of industries.

This means that the promotion of this type of electrode involves two things, above all else:

1. Familiarity with its important advantages, and

2. Being on the alert in customers' plants for applications calling for the use of "low hydrogen" electrodes.

At present "low hydrogen" electrodes represent but a fraction of the total market for welding electrodes. Yet, the introduction of the "low hydrogen" electrode is beyond question the greatest development which has taken place in the field of arc welding electrodes since the advent of the E6011 type. With it, it is possible to do many things heretofore considered impossible or possible only under extreme difficulty, or at great expense.

It is true that because the operating characteristics are different than those to which industry is accustomed, there has been some reluctance on the part of operators to accept these electrodes. But the differences in welding procedure are so minute---and are so easily picked up---that they stand as nothing in relation to the very important user benefits that "low hydrogen" electrodes bring to many arc welding applications.

Making this picture clear and convincing to your customers, whenever the occasion presents itself represents a real service to them--the kind of service which creates the best type of good will for you and your company.

<u>SPECIAL NOTE</u>:

Since hydrogen is produced from moisture, if present in the coating, great care is exercised in producing Airco "low hydrogen" electrodes as dry as possible. Therefore, it is important that these electrodes be afforded appropriate protection to avoid pick-up of excessive mositure either during shipment or while in storage. If low hydrogen electrodes pick up excess moisture, it is recommended that they be dried out in an oven. Consult Electrode Pocket Guide for reconditioning procedures.

AIRCO NICKEL BEARING, LOW ALLOY,

LOW HYDROGEN, IRON POWDER ELECTRODES

CODE-ARC 8018-C1, C2 AND C3

All of the nickel-bearing electrodes listed conform to the requirements of the AWS Specification A5.5-69T. The Code-Arc 8018-C3 is also approved by the Naval Ship Engineering Center under Spec. MIL-E-22200/ID and appears on the Qualified Products List as a MIL 8018-C3 type.

These nickel-bearing electrodes are used when welding most low alloy steels in the 70,000 and 80,000 psi tensile range where good impact properties (toughness) at sub zero temperatures are the prime requisite. Being iron powder, low hydrogen types, they offer high deposition rates along with excellent x-ray quality deposits.

Code-Arc 8018 C1 is designed to weld 2 1/4% to 3 1/2% nickel steels such as Lukens LT 75, U.S.S. Char-Pac and Bethlehem ROC-60 without preheat in most instances. Air hardenable steels both cast and wrought can be welded with minimum preheat and controlled welding conditions.

TYPICAL MECHANICAL PROPERTIES - UNDILUTED WELD METAL TESTED IN CONFORMANCE WITH AWS SPEC A 5.5-69T

	CODE-ARC 8018-C1	AWS REQUIREMENTS
Tensile Strength, PSI	83,000	80,000 min.
Yield Strength, PSI	73,000	67,000 min.
Elongation, % in 2"	30	19 min.
Charpy V Notch Ft. lb at -75°F.	55	20 ft. lb at -75°F.

Specimens were stress relieved 1 hour at 1150°F. ± 25°.

Chemical	C	Mn	P	S	Si	Ni
Analysis %	0.05	0.97	0.014	0.016	0.33	2.32

Code-Arc 8018-C2 is designed to weld 2% to 4%
wrought and cast steels for low temperature or norm
service when superior notch toughness of the weld d
required. Preheat should be employed when welding
hardenable to eliminate quench cracking tendencies
heat affected zones.

TYPICAL MECHANICAL PROPERTIES - UNDILUTED WELD
TESTED IN CONFORMANCE WITH AWS SPEC A 5.5-

	CODE-ARC 8018-
Tensile Strength, PSI	88,000
Yield Strength, PSI	77,000
Elongation, % in 2"	29
Charpy V Notch, Ft. lb. at -100°F.	43

Specimens were stress relieved 1 hour at 1150°

Chemical	C	Mn	P	S	
Analysis %	0.05	0.72	0.012	0.016	0.

Code-Arc 8018-C3 has excellent low temperature
and adequate tensile strength for welding ASTM mate
A148-65 Grades 80-40 and 80-50; A236-65 Classes C,
A302-67 Grades C and D; and trade name steels such
Mayari R, LT75, N-A-X High Tensile, V-55 and Yoloy

Typical "all weld metal" mechanical properties
welded" and "stress relieved" conditions tested in
to Spec. MIL-E-22200/ID are:

	AS WELDED	STRESS RELIEVED
Tensile Strength, PSI	83,000	82,000
Yield Strength, PSI	72,000	71,000
Elongation, % in 2"	31	29
Charpy V Notch, Ft. lb. at -20°F.	81	83

Specimens were stress relieved 2 hours at 1150°F

Chemical	C	Mn	P	S	
Analysis %	0.04	0.90	0.013	0.014	0

When welding some of the trade name steels men
will remain in the bare state (sometimes called wea
8018-C1 or 8018-C2 electrodes are recommended.

AIRCO CHROME MOLY, HIGH SPEED, LOW HYDROGEN, LOW ALLOY, IRON POWDER ELECTRODE

CODE-ARC 8018-B2, 8018-B2L

CODE-ARC 9018-B3, 9018-B3L

Four new, high-quality, chrome moly electrodes are introduced for welding the high temperature service steels in the steam power generating, petroleum, petrochemical, pressure vessel and pressure piping industries. They are Code-Arc 8018-B2, 8018-B2L (1 1/4% Cr - 1/2% Mo), and Code-Arc 9018-B3, 9018-B3L (2 1/4% Cr - 1% Mo). It is estimated the total annual market for these electrodes is five (5) to six (6) million pounds. With these new products we expect to obtain a sizable share of this potential.

CODE-ARC 8018-B2 AND 8018-B2L

These low hydrogen, low alloy, iron powder electrodes are designed to weld pipe, casting, forgings and plate of the 1/2% Cr - 1/2% Mo, 1% Cr - 1/2% Mo and 1 1/4% Cr - 1/2% Mo heat resistant steels. They can be used in all welding positions with AC or DC reverse polarity. Cleaning the joint area prior to welding is imperative and the use of preheat and postheat treatments may be required, depending on the type and thickness of the base material to be welded.

TYPICAL MECHANICAL PROPERTIES - UNDILUTED WELD METAL

CODE-ARC 8018-B2

	AC	DCR	AWS A 5.5 Specification
Tensile Strength, PSI	100,000	95,000	80,000 min.
Yield Strength, PSI	89,000	84,000	67,000 min.
Elongation, % in 2"	25	26	19 min.

Specimens were stress relieved at 1275°F. for one hour

Chemical	C	Mn	Si	P	S	Cr	Mo
Analysis %	0.06	0.65	0.60	0.013	0.014	1.25	0.48

CODE-ARC 8018-B2L

	AC	DCR	AWS A 5.5 Specification
Tensile Strength, PSI	89,000	88,500	80,000 min.
Yield Strength, PSI	78,000	76,500	67,000 min.
Elongation, % in 2"	26	27	19 min.

Specimens were streee relieved at 1275°F. for one hour.

Chemical	C	Mn	Si	P	S	Cr	Mo
Analysis %	0.034	0.53	0.66	0.013	0.014	1.25	0.48

The key to success lies in knowing <u>WHERE</u> and <u>HOW</u> **TO APPLY** your knowledge.

May we suggest that you start planning your campaign, while whatever new information you have acquired is still fresh in your mind. Jot down the names of prospects that may have occurred to you while you are attending this training session.

DO IT NOW!

PROSPECTS	SPEAK TO
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SECTION D

STAINLESS STEEL WELDING

Stainless steel electrodes represent an important phase of Airco's line of electrodes because of their high unit price and their relatively large volume. However, the production of stainless steel electrodes is far complex than the production of carbon and low alloy steel electrodes. Since stainless steels are used under critical service conditions and the price of these steels is high, it follows that the quality of the electrodes must be of the highest order. The various steps followed in the production of the Airco stainless steel electrodes assures the customer of the required analysis and operating properties.

BASE METAL

Stainless steel is essentially a steel base to which large amounts of chromium and nickel are added. The addition of 15% or more of chromium gives stainless steel its corrosion resistance, or the ability to stay shiny and bright. However, the addition of chromium also produces an alloy which is difficult to process and fabricate, and to overcome this about 8% nickel is also added to the steel, which results in a type of stainless known as 18-8. This alloy is easy to process in the steel mill and also is easy to fabricate. Because of these excellent properties 18-8 stainless steel is the base or starting point for most of the stainless steels used in this country. Slight variations in the chemical components of type 18-8 stainless have resulted in the following group of A.I.S.I. alloys, of which types 302 and 304 are the most popular for fabrication work:

A.I.S.I.	301	A.I.S.I.	303
	302		304
	302B		304L (extra low carbon)

From experience in the food and chemical industries, it was found that the simple 18-8 varieties of stainless suffered in certain applications from severe general corrosion and in others

from deep localized pitting. Metallurgists have discovered that this pitting could be eliminated by adding molybdenum in amounts of 2 to 4%. To properly balance this analysis, it was found that a little more nickel---about 12%---is also needed. This stainless, known as 18-12 MO (Type 316), has excellent corrosion resistance, particularly against pitting. It should be remembered that type 316 is not simply an improved general purpose stainless steel but is designed for special purposes only, which justify its higher cost.

The chromium limits and other chemistry found in the three classifications of stainless steel are as follows:

Martensitic	% Cr minus 17 X % C is less than 12.5%
Ferritic	% Cr minus 15 X % C is greater than 12.5%
Austenitic	C 0.1 nominal, Ni 6-36%, Cr 14-30 (Ni + Cr greater than 24)

The above figures are approximate and serve to indicate the overlapping of the martensitic and ferritic stainless steels which the carbon and chromium influence.

The selection of the proper electrode for stainless steel application is in most cases a more critical choice than with mild steel because of the number of types and grades of stainless steel and the varying degrees of severity of heat, corrosion media, etc., to which the weldment will be subjected. Selecting the right electrode for most satisfactory results is a matter of analyzing all the conditions applying to the particular job. To determine the right type and size of electrode best suited to a given set of condtions the following factors must be considered:

1. The analysis of the base metal to be welded.
2. Dimensions of the section to be welded.
3. Type of welding current available.
4. Welding position or positions to be used.
5. The fit-up of the section to be welded.
6. Specific properties required of the weld deposit.
7. Requirements of a specific code, standard or specification.
8. Selection of the electrode must be exercised carefully because the high cost of the material to be welded.
9. Not only must the stainless steel weld metal have sufficient tensile strength and ductility but it must also have corrosion resistance equivalent to the parent metal. Hence, an electrode having an analysis comparable to the base metal should be used.

A large percentage of stainless steel welding is performed on light gauges and therefore the electrode must have the proper penetration to insure a 100% weld without allowing the arc heat to burn away the joint edges. The stainless steel electrode should produce a smooth weld bead which will require a minimum amount of grinding, and after polishing, the weld metal should match perfectly with the color of the parent metal. Airco has engineered all of these qualities into its line of stainless steel electrodes.

Airco stainless steel electrodes (which have a stainless steel core wire) are available with three coating types, lime (15) for DC reverse polarity, Titania (16) for AC or DC welding, and our new EASYFILL™ TYPE for DC reverse polarity welding.

The lime type of coating is designed to give good operating characteristics for all position welding. The lime type of electrode produces convex beads which are desirable for root passes where the full throat section prevents cracking. The fast setup of weld metal by this coating provides easy operation in both the vertical and overhead positions. The electrode covering produces a slag which completely covers the weld, provides rapid wetting action and produces welds with a minimum amount of spatter. The coating also flushes the impurities from the weld metal thereby producing a deposit free from porosity and having mechanical and corrosion-resistant properties of the quality expected of the particular type. The 1/8" or smaller electrodes are exceptionally well adapted for welding vertically down.

The AC-DC coating is designed to produce welds of high quality in all positions using either AC or DC reverse polarity. The AC-DC coated electrodes have the most operator appeal because of the smooth arc action, exceptional bead appearance and very easy slag removal. When using Airco AC-DC stainless steel electrodes you get excellent starting characteristics with all types of AC welding equipment. Welding characteristics are outstanding on either AC or DC. The arc is stable and smooth; the spray type transfer produces uniform, full throated beads. The smooth beads allow complete slag removal which is so essential to obtain the maximum degree of corrosion resistance. The slag

is easily removed with ordinary hand tools and is accomplished without leaving a secondary film. This, together with the smoother, slightly concave welds produced by the AC-DC electrode, means less cleaning, grinding, and polishing time than for the lime type. The AC-DC stainless electrode is generally preferred for shops where only one type of coating is stocked.

The EASYFILL type electrode is the premium electrode for downhand welding---DCRP. It is not for vertical or out-of-position work -- rather it is specifically designed to increase production of horizontal fillet welds, butt welds and other downhand stainless welding, without sacrificing quality. EASYFILL welds are self-slagging. EASYFILL fillets have flat contours with edges that blend into the fillet legs. There is no excess weld bead to be ground, minimal grinding needed before polishing.

Why Can You Realize One Third Cost Savings?

Simply because EASYFILL welds have flat profits. The metal is in the joint where it belongs, not in excess weld bead.

You save two ways:

A. You would use 30% less electrodes for the same number of inches fillet weld.

B. You would save 33% on labor since it would take you that much less time to make the same weld as with conventional AC-DC electrodes.

CONTROLLED FERRITE FOR STAINLESS STEEL

WELD METAL

Foremost among the requirements of a good arc-welding electrode is a crack-free deposit. One of the most effective ways of controlling the crack-sensitivity of stainless weld deposits normally having ferrite containing micro-structures is to control the ferrite levels. Because close control of the ferrite content of austenitic stainless weld deposits was needed in many applications, an accurate method of ferrite measurement and calculation was required.

During the Second World War the high chromium-to-nickel ratio of the Type 308 weld metal was found to be more crack resistant than those compositions with lower chromium-to-nickel ratios. The logical relationship between the weld metal and the balance of the austenite-forming elements and the ferrite-forming elements was quickly recognized. A. L. Schaeffler, in his studies on the use of austenitic electrodes for welding dissimilar metals, developed the very useful and widely accepted "Schaeffler" diagram.

The Magne-gauge method of determining ferrite is now gaining prominence as an instrument for measuring ferrite content.

The stainless steel weld metal deposit, whether made by covered electrodes or bare wire filler metal, can be adjusted by electrode manufacturers to have a ferrite containing micro-structure most resistant to hot-cracking. This is accomplished by maintaining the ferrite-forming elements, such as chromium and molybedenum, at the high side of their allowable range and the austenite forms, such as nickel, at the low side. It is the balance between these elements which determines the amount of free-ferrite in the micro-structure of the weld deposit.

CARBIDE PRECIPITATION

It has also been found from experience that the plain 18-8 stainless steels have a characteristic which can cause trouble in some applications. When heated in the range of from 800 to 1500°F., a metallurgical change takes place which robs the metal of some of its corrosion resistant qualities. This change is first noticed as corroded bands when welded 18-8 stainless steel is exposed to a corrosive agent. The steel is attacked and eaten away parallel to the weld, not in the bead but a short distance away, in the heat affected zone--as shown in Figure 2.

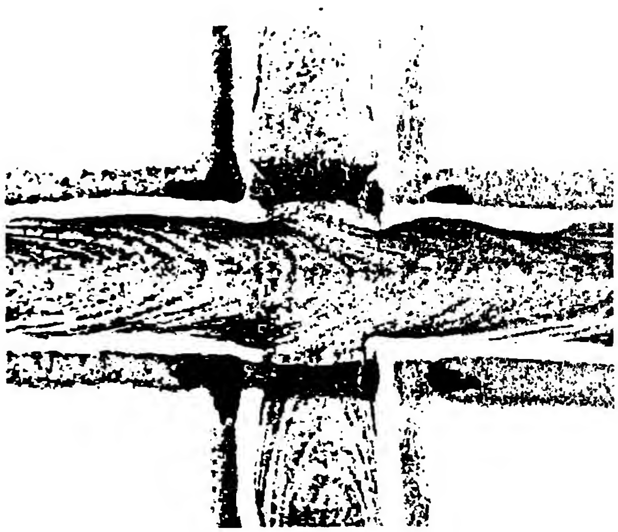

Figure 2 - Carbide precipitation clearly shown paralleling beads of type 308 weld metal on type 304 stainless plate.

This metallurgical reaction in the heat affected zone is called carbide precipitation. Carbide precipitation can be corrected by heat-treating all 18-8 weldments to get the carbon back into solution where it belongs. Heat treatment, however, is an expensive means of eliminating corrosion from carbide precipitation. The second but less common way is to limit the carbon content of the stainless steel to .03% or less. This is called "extra low carbon" stainless and as it contains so little carbon, there can be no corrosion problems from carbide precipitation.

A simpler and more widely used method is to add a small amount of titanium or columbium to the steel (Figure 3), which "mixes" with the carbon and keeps it "tied-up" under all conditions---even in the heat affected zone. Because of its lower cost steel mills prefer titanium to columbium additions. For this reason type 321, consisting of 18 Cr - 8 Ni stainless with a small amount (less than 1/2%) of titanium, is the most common "stabilized" type of base metal used.

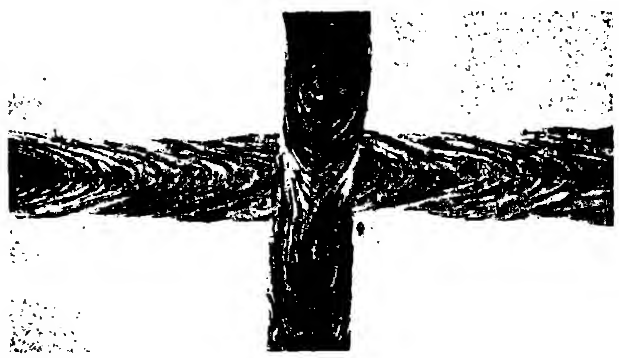

Figure 3 - Shows freedom from carbide precipitation when using type 19-9 Cb weld metal on 18-8 stabilized (type 321) stainless plate.

STRAIGHT CHROMIUM STEELS

The straight chromium steels are produced by adding only chromium, in varying quantities, to a carbon steel base. In the three basic types, the chromium contents are 12, 16 and 28%. As they contain no nickel they are cheaper than the stabilized grades and are used extensively for low cost applications such as automobile body trim. However, as previously mentioned, straight chromium steels are not as easy to weld as chrome nickel stainless. Also, straight chromium stainless steels usually require pre-heat and post-heat treatment.

Refer to your Electrode Pocket Guide for the recommended electrodes for the welding of the straight chrome steels.

GROUPING OF STAINLESS STEELS

From the previous discussion it is possible to classify all of the stainless steels into three general groups:

I. Unstabilized Steels
- The plain 18-8 types.
- The 18-12 type containing molybdenium.

II. Stabilized Steels
- The stabilized 18-8 types or the extra low carbon type which give the same results.

III. Straight Chromium
- The straight chrome types such as the 12% Cr, 16% Cr and 28% Cr.

SELECTION OF ELECTRODES

If welding electrodes were used which deposited weld metal with the exact analysis as that of the base metal, the weld metal would be likely to crack and the corrosion properties of the weld would be inferior to those of the base metal. To overcome cracking and corrosion difficulties the electrodes are made so that they will deposit more chromium and nickel than is found in the base metal. This explains the reason for the existence of 19 Cr - 9 Ni electrodes when base metals are usually of the 18 Cr - 8 Ni type. By adding additional chromium and nickel, the electrodes (with 19 Cr - 9 Ni) can be used to weld all of the plain 18-8 grades of stainless steels without danger of cracking.

Because molybdenium is so important for minimizing pitting in 18-12 Mo (Type 316) stainless steel, the matching electrode must also contain molybdenum together with 12% nickel to balance the composition. The Airco designation for this electrode is Type 316.

ELECTRODE FOR STABILIZED BASE METALS

When welding stabilized stainless base metals containing titanium or columbium -- 18-8 Ti (Type 321) or 18-8 Cb (Type 347)-- stabilized electrodes must be used. These stabilized electrodes contain columbium which, unlike titanium, transfers across the arc to "tie-up" the carbon. For this reason the proper electrode to use on Type 321 or 347 stainless steel is 19-9 Cb (Type 347). Even though 19-9 Cb electrodes cost a little more than plain 19-9 electrodes, many fabricators use them to weld both the plain 18-8 type and the stabilized types 321 and 347 of stainless. While this is common practice, there is no advantage in using stabilized electrodes on unstablized stainless steel.

ELECTRODES FOR STRAIGHT CHROMIUM BASE METALS

When welding the straight chrome types of base metal, the corresponding type of straight chrome electrode should be selected; i.e. the 12% Cr types of stainless steels are welded with 12% Cr electrodes.

EXTRA LOW CARBON STAINLESS

Although not used extensively, the extra low carbon stainless base materials require electrodes of the extra low carbon type. Thus 19-9 ELC is recommended for welding 304L stainless, while 19-9 Cb can be used as second choice.

TITANIA VS LIME COATINGS

The two currently popular coatings for stainless steel electrodes are referred to as "titania" and "lime". All LIME coatings contain titania and all TITANIA coatings contain lime. The determining factor is whether lime or titania predominates. Metallurgically there is no difference in their weld metals, but the titania type has greater operator appeal.

The TITANIA Type, containing titania (or titanium dioxide*), is designed for AC or DC reversed polarity and can produce a thin concave bead, as illustrated in Figure 4, because of its smoother arc and better wetting action. Thus the "stretched-out" titania bead gives greater footage and is excellent for welding thin sections which are not subject to great strain. The smooth bead does not require extensive grinding to obtain a high polish on products such as kitchen and dairy equipment. To make a thicker bead the operator should slow down somewhat in his welding speed and allow the metal to pile up. This points out the exceptional flexibility of Airco Titania stainless electrodes--either long, stretched-out beads or shorter, thick-throated beads can be made.

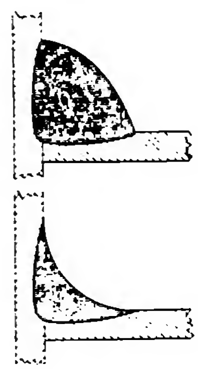

Figure - Above: Typical cross section with Lime Coated Electrode.
Below: Typical cross section with Titania Covered Electrodes.

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*Titanium dioxide is a white pigment used extensively in paint. In this natural state it is tan in color and is called rutile, which is used as a coating for the E6012 and E6013 electrodes.

The LIME type coating, designed for DC reversed polarity produces a weld metal with the same metallurgical composition as that of titania. However, it lacks the flexibility of the latter. A welder using lime coated electrodes has no choice but to put in a thick weld (Figure 4) because this electrode deposits a convex bead. This characteristics has given some the impression that welds made with lime coatings are superior in strength to those made with titania. They overlook the facts that 1) both types of coating produce identical weld metal, and 2) the flexibility of titania enables the welder to put in either a thin or a thick bead.

Here are the major differences between the titania and the lime coated electrodes:

- The lime type is designed to operate on DC reversed polarity.
- The titania type electrodes operate on AC or DC reversed polarity. Only one type of electrode is needed in shops using both AC and DC current.
- The lime electrode gives a more convex bead than the titania type.
- The titania electrodes produce smoother, slightly concave beads, which result in greater footage per electrode than with the lime type.
- The titania electrodes have much smoother arc action on DC than the lime type.
- Slag removal is much easier when using titania electrodes than when using the lime type. One of the reasons is that the titania electrode beads are smoother and have better wash-in qualities at the edges so the slag cannot adhere as tenaciously as with lime electrodes.
- The titania electrodes provide greater flexibility than lime types.

From the above comparison it is easy to understand why the titania coated electrodes have gained in popularity over the lime coated types. Whenever a customer is in doubt as to which type to use you are perfectly safe in recommending titania.

WELDING PROCEDURES FOR

STAINLESS STEEL ELECTRODES

As a general rule, an electrode with either the AC-DC or plain DC coating, which gives a weld deposit comparable to the base metal analysis, should be used. The same general operating procedure will be applied to both the AC-DC and DC types of electrodes. However, it may be necessary to employ slightly higher currents when operating on AC than when using DC reverse polarity. In either case a short arc should be maintained. The low thermal conductivity and the high expansion of stainless steels require that the welding current be kept as low as possible or the travel speeds kept high to reduce warping, as stainless steels expand 50% more and conduct heat away 50% slower than mild steel. Lower welding currents than used for mild steel are required because the electrical resistance of the electrode core wire is 6-9 times higher than mild steel, while the melting temperature is approximately 200^{o}F less.

For welds in the flat position, stringer beads are recommended and weaving, if required, should not exceed 2 or 3 times the electrode diameter. Although it may be necessary to weave on vertical welds, the width of the weave should be kept to a minimum.

The arc length should be as short as possible without touching the molten pool with the electrode covering. The use of a long arc would permit oxidation of some of the alloying elements, thereby changing the analysis of the deposited metal. In addition, the deposition efficiency would be decreased and the spatter loss increased. Airco stainless steel electrodes will consistently produce welds possessing good corrosion resistance, and welds will exhibit excellent mechanical properties and X-rays.

EDGE PREPARATION

When welding butt joints without backing, in plate material 3/16" and less, the plate should be prepared with a sheared edge. A gap of about 1/2 the thickness of the plate should be left between the two sections. On plate 3/16" to 1/2" in thickness the edges should be beveled, while over 1/2", a "U" groove should be used.

DOWNHAND WELDING

In welding butt joints in the flat position, the current selected should be high enough to insure ample penetration with good "wash-up" on the sides. When several beads are required it is advisable to use a number of small beads rather than to try to fill up the groove with one or two passes. A fairly short arc should be maintained, and any weaving should be limited to 2-1/2 times the electrode diameter. In general, it is good practice to hold the electrode vertical or very slightly tilted in the direction of travel. The latter case should only be used with small diameter electrodes. For lack of a hard and fast rule it may be said that the correct position is one that gives a clean pool of metal and which solidifies uniformly as the work progresses. The movement of the electrode across the pool controls the flow of the metal and slag. Any weave technique employed should be in the form of a "U" for best results.

VERTICAL WELDING

The welding of butt joints in the vertical position progressing upward can be accomplished with a reduced current from that used in the flat position for a given electrode diameter. The current selected should be nearer the minimum range suggested in the following table. Oscillation or whipping is not recommended but instead a motion in the form of a "V" may be used for the first pass. The point of the "V" is the root of the joint, hesitating momentarily at this point to assure adequate penetration and to bring the slag to the surface. The arc is then brought out on one side of the joint about 1/8" and immediately returned to the root of the joint.

After the momentary pause at the root the procedure is repeated on the other side of the weld. Electrodes of 3/16" in diameter may be used on sections heavy enough to give rapid dissipation of the heat, but 5/32" diameter electrodes are the generally accepted maximum size for less massive sections. Welding should progress from the bottom upward except for single pass corner welds with 3/32" and smaller diameter electrodes, which may be used from the top downward. In the usual vertical fillet weld the electrode is inclined slightly below the horizontal position (holder end lower than arc end) and the weave motion should be rapid across the center of the bead.

OVERHEAD WELDING

Stringer beads are recommended when welding in the overhead position, since attempts to carry a large puddle of molten metal will result in an irregular convex bead. To assure best results, a short arc should be maintained and the machine should be set properly thereby providing good penetration of the base metal.

HORIZONTAL FILLET WELDING

Horizontal fillet welds and lap welds require a machine setting high enough to give good penetration into the root of the joint and a well-shaped bead. Too low a current is easily recognized, since difficulty will be experienced in controlling or concentrating the arc in the joint, and a very convex bead with poor appearing fusion will result. When two legs of equal thickness are being welded, the electrode should be held equidistant from each face and tilted slightly forward in the direction of travel. If one leg is lighter than the other, the electrode should be pointed towards the heavier leg. Undercutting on the vertical is caused by dwelling too long on that leg or by too high a current.

The proper selection of electrode size and welding currents is very important in welding chromium nickel alloys due to their high coefficient of expansion. In general, a small diameter electrode and lower current amperage should be used than on corresponding sizes of mild steel shapes or plates, for this will

help reduce the amount of distortion. Rapid cooling of the weld metal and parent metal adjacent to the line of fusion is essential to reduce the annealing effect of the welding heat and to minimize carbide precipitation in the parent metal. Use of a copper backing strip and rigid clamping fixtures will aid materially in keeping warpage to a minimum.

REMINDER

It is well to keep in mind that the recommended instructions for the electrode should be followed in all cases. The welding of stainless steel is a more critical operation than welding mild steel, and the results of error are costly due to the price of the base metal. Before welding, all edges should be clean and free from foreign matter. When cleaning welds or plate edges it is wise to use a stainless steel scratch brush.

HEAT TREATMENT

Preheat and inter-pass temperature control and stress relief are not normally required when welding any of the 300 series (austenitic) stainless steels. However, preheat and inter-pass temperatures in the 300-to-800°F. range are recommended when welding the 400 and 500 series stainless steels. The chromium content determines the temperature and method of cooling for stress relief which is usually a sub-critical anneal in temperature ranges of 1250 to 1550°F. A full anneal requires temperatures about 300°F. higher than stress relieving temperatures. These heat treatments should be used with caution as they will cause carbide precipitation and reduced corrosion resistance.

GENERAL INFORMATION

The chromium nickel stainless steels have a coefficient of expansion approximately twice that of mild steel and a thermal conductivity approximately one-half of that of mild steel. The higher coefficient of expansion greatly increases the tendency for warping, and the lower thermal conductivity confines the heat to a much smaller area adjacent to the weld than does mild steel. The localized heating also increases the carbide precipitation adjacent to the weld, which is very pronounced in unstabilized stainless steels at temperatures between 800°F. and 1500°F. The extent of the precipitation is determined by the temperature and the time the material is maintained in that temperature range.

To keep carbide precipitation to a minimum, the heat input should be kept at a minimum and the cooling rate of the weld should be at the maximum. It should be pointed out that the precipitation of the carbides at the grain boundaries does not materially effect the mechanical properties; <u>however, it does materially effect the corrosion resisting properties</u>. As the corrosive agent reacts with the carbides much faster than it does with stainless steel, the bond between the stainless steel crystals is continually reduced and after sufficient time, the crystals of stainless steel are completely freed from adjacent crystals. <u>A thorough knowledge of the particular application should be known and the above characteristics considered when making recommendations for stainless steels for any given corrosion condition</u>.

It is always advisable to tack adequately the assembly prior to welding if distortion is to be kept low. Better still would be to place the work in a jig that would rigidly hold the material in place.

The most frequently used stainless steels are a combination of the aforementioned elements, with iron, carbon, manganese and silicon. For a given combination of type of steel, consideration must be given to the conditions under which the material is to be used. As pointed out previously, different thermal conditions will produce different metallurgical structures. For example, 18-8 stainless steel, under most condistions, will be austenitic, however, the proper mechnaical and thermal treatment can make this material martensitic. <u>A good knowledge of the steel's characteristics is necessary to know what the end product will be</u>.

Generally speaking, if the nickel content is above 50% of the chrome content in a high chrome steel, the material will be austenitic. However, if the nickel content is only 50% of the chrome content, the material may be partly ferritic. If the nickel content is increased to 75% or 80% of the chromium content, as it is in 25-20, the material will, under normal conditions, be austenitic. <u>This characteristic is advantageously used in the selection of a general purpose stainless steel electrode for</u> welding some hard to weld materials. The 25-20 electrode is used extensively for:

- Welding high hardenable steels, high carbon steels and chromium steels where preheating is impossible.

- Welding other such materials where a high strength, ductile weld is desired.

WELDING OF CHROME STEELS

The welding of the straight chromium steels is much more difficult than the welding of the chrome nickel steels. The coefficient of expansion and thermal conductivity of the chrome steels is very similar to that of mild steel; note that these properties are virtually opposite to those for chrome nickel stainless. As stated previously, chromium increases the hardness of steel, therefore, it is necessary that a preheat of from 300°F. to 500°F. be used to eliminate cracking. <u>If a preheat is not possible, then a 25-20 electrode should be used for making the weld</u>.

Adjacent to welds made on straight chrome steels, there is a zone in which grain growth has taken place and the material is very hard. The hardness of this zone and of the weld is very close to what would be obtained had the material been quenched from 1,550°F. The hardness can be reduced some by a stress relief treatment, in which the material is slowly cooled after being held for two hours at 1,250°F. or 1,400°F., depending upon the composition. However, to reduce the hardness to approximately 150 Brinell, it is necessary that the material be slowly cooled from 1,550°F. The grain size of the heat-affected zone adjacent to the weld, cannot be reduced by heat treatment; it can only be reduced by mechanical work. As the mechanical work is frequently impossible, the heat input should be kept to a minimum, thus keeping the grain size small by keeping the temperature of the parent metal adjacent to the weld below the critical temperatures as much as possible. An excessive heat input will not only increase the width of the heat-effected zone, but will also increase the grain size within the zone.

Generally speaking, it is good practice to have the composition of the metal in the weld the same as the plate material, thus eliminating possible electrolytic action between the dissimilar materials. In some cases, it will be necessary to weld straight chrome steels with 25-20 electrodes. Experience has proven that in this case the corrosion resulting from the dissimilar metals is almost nil, therefore, this practice can be safely recommended. Straight chromium steels find wide application in the petroleum, sulphur and other industries where

corrosion resistance is desired and the corrosive agent is not too strongly acidic. Generally speaking, chrome nickel steels are used where the corrosive agent is strongly acidic.

The question may be raised, why then use chromium steels if the more easily welded chrome nickel steels will satisfactorily do the job? The answer to this question is purely one of economics. The straight chrome steels contain less alloys and naturally cost less. Where facilities permit the thermal treatment required by straight chrome steel, it may be found to be cheaper to use the straight chrome steels than chrome nickel. If thermal treating facilities are not available, it may be necessary to use a chrome nickel steel.

STAINLESS STEEL BASE METALS

The analysis of stainless steels have been standardized and listed by type numbers established by the American Iron and Steel Institute (AISI). The listing of AISI types are given on Table 1.

Doubtless many will immediately recognize that several type numbers in wide use industrially do not appear in this list. This is explained by the fact that it takes a considerable period of time to get an analysis accepted for inclusion as a standard type. During this "waiting period" it is necessary to develope the fundamental data on the composition. This would include the ranges of the chemical analysis, mechanical properties as well as service performance. This also explains why, at times it is difficult to "pin down" the specific analysis and properties of new types of stainless steel.

AWS CLASSIFICATIONS

The AWS specification applicable to stainless steel electrodes is known as "Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes." It is published jointly by the AWS and the American Society for Testing Materials and carries AWS designation A5.4-55T and ASTM designation A298-55T. The system of classification numbers used

is made up of the letter E to indicate electrodes; following this is a number e.g. 308, which represents the AISI type number of the analysis; finally following a dash are two digits which indicate the type of current and welding positions for which the electrode is usable as follows:

E xxx-15	DC	F, V, OH, H
E xxx-16	AC-DC	F, V, OH, H

Airco stainless steel electrodes are of the "15" or "16" types, the former being the lime types, the latter the titania types.

MARKETS

In general, the fields for stainless steels and stainless steel electrodes are quite obvious---wherever corrosion and heat resistance is required.

The chromium nickel alloys find extensive application in the chemical, food and dairy industries---and to a somewhat lesser extent they are used in power plants.

The straight chromium alloys are currently recommended as substitutes for the scarce chromium nickel groups---hence they may be encountered in the same fields mentioned above. Normally the straight chromium steels are used for their resistance to scaling and high strength at elevated temperatures. For that reason these electrodes are used in sizeable quantities in power plants, aircraft engine plants, refineries and other industries where high temperatures are common service conditions.

Table 1

STANDARD AND TENTATIVE STANDARD TYPES STAINLESS AND HEAT RESISTING STEELS CHEMICAL RANGES AND LIMITS

Type Number	Chemical composition, per cent					
	C	Mn Max.	Si Max.	Cr	Ni	Other Elements
301	Over 0.08/0.20	2.00	1.00	16.00/18.00	6.00/8.00	——
302	Over 0.08/0.20	2.00	1.00	17.00/19.00	8.00/10.00	——
302B	Over 0.08/0.20	2.00	2.00/3.00	17.00/19.00	8.00/10.00	——
303	0.15 Max.	2.00	1.00	17.00/19.00	8.00/10.00	Note 3
304	0.08 Max.	2.00	1.00	18.00/20.00	8.00/11.00	——
304L	0.03 Max.	2.00	1.00	18.00/20.00	8.00/11.00	——
305	0.12 Max.	2.00	1.00	17.00/19.00	10.00/13.00	——
308	0.08 Max.	2.00	1.00	19.00/21.00	10.00/12.00	——
309	0.20 Max.	2.00	1.00	22.00/24.00	12.00/15.00	——
309S	0.08 Max.	2.00	1.00	22.00/24.00	12.00/15.00	——
310	0.25 Max.	2.00	1.50	24.00/26.00	19.00/22.00	——
310S	0.08 Max.	2.00	1.50	24.00/26.00	19.00/22.00	——
314	0.25 Max.	2.00	1.50/3.00	23.00/26.00	19.00/22.00	——
316	0.10 Max.	2.00	1.00	16.00/18.00	10.00/14.00	Mo 2.00/3.00
TS 316	0.10 Max.	2.00	1.00	16.00/18.00	10.00/14.00	Mo 1.75/2.50
316L	0.03 Max.	2.00	1.00	16.00/18.00	10.00/14.00	Mo 1.75/2.50
317	0.10 Max.	2.00	1.00	18.00/20.00	11.00/14.00	Mo 3.00/4.00
321	0.08 Max.	2.00	1.00	17.00/19.00	8.00/11.00	Ti 5xC Min.
347	0.08 Max.	2.00	1.00	17.00/19.00	9.00/12.00	Cb 10xC Min.
TS 347	0.08 Max.	2.00	1.00	17.00/19.00	9.00/12.00	Cb 8xC Min.
TS 347A	0.08 Max.	2.00	1.00	17.00/19.00	9.00/12.00	Cb-Ta 8xC Min.
403	0.15 Max.	1.00	0.50	11.50/13.00	——	——
405	0.08 Max.	1.00	1.00	11.50/13.50	——	Al 0.10/0.30
410	0.15 Max.	1.00	1.00	11.50/13.50	——	——
414	0.15 Max.	1.00	1.00	11.50/13.50	1.25/2.50	——
416	0.15 Max.	1.25	1.00	12.00/14.00	——	Note 3
420	Over 0.15	1.00	1.00	12.00/14.00	——	——
430	0.12 Max.	1.00	1.00	14.00/18.00	——	——
430F	0.12 Max.	1.25	1.00	14.00/18.00	——	Note 3
431	0.20 Max.	1.00	1.00	15.00/17.00	1.25/2.50	——
440A	0.60/0.75	1.00	1.00	16.00/18.00	——	Mo 0.75 Max.
440B	0.75/0.95	1.00	1.00	16.00/18.00	——	Mo 0.75 Max.
440C	0.95/1.20	1.00	1.00	16.00/18.00	——	Mo 0.75 Max.
446	0.35 Max.	1.50	1.00	23.00/27.00	——	N 0.25 Max.
501	Over 0.10	1.00	1.00	4.00/6.00	——	——
502	0.10 Max.	1.00	1.00	4.00/6.00	——	——

NOTE 1. TS 316, TS 347 and TS 347A are tentative standard type numbers; the remainder of the type numbers are standard type numbers.

NOTE 2. The maximum phosphorus and sulphur contents of 304L, 309S, 310S, 316L, TS 316, TS 347 and TS 347A are 0.04 and 0.03 per cent, respectively; the maximum phosphorus and sulphur contents of the remaining type numbers, except 303, 416 and 430F, are 0.040 and 0.030 per cent, respectively.

NOTE 3. Phosphorus or sulphur or selenium, 0.07 per cent minimum; zirconium or molybdenum, 0.60 per cent maximum.

NOTE 4. The maximum content of molybdenum of 2.50 per cent in 316L and TS 316 is established in accordance with National Production Authority Order M-52 March 31, 1951.

NOTE 5. The minimum ratio of columbium to carbon in TS 347 of not greater than 8 to 1 and the minimum ratio of columbium-tantalum to carbon in TS 347A of not greater than 8 to 1 are established in accordance with National Production Authority Order M-3 as amended March 15, 1951.

FACT SHEET

Covered Electrodes Recommended

201	202	301	302	302B	303(a)	304	304L	305	308	309	309S	310	310S	314	316	316L	317	317L (b)	321	330(b)	347
E308(c)	E308(c)	E308(c)	E308	E308	E308; E312	E308	E308	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
	E308(c)	E308(c)	E308	E308	E308; E312	E308	E308	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
		E308(c)	E308	E308	E308; E312	E308	E308	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
			E308	E308	E308; E312	E308	E308	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
				E308	E308; E312	E308	E308	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
					E308; E312	E308; E312	E308; E312	E308; E312	E308; E312	E308; E312	E308; E312	E312	E312	E312	E308; E312	E308; E312	E308; E312	E308; E312	E308; E312	E312; E309	E308; E312
						E308(n)	E308	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
							E308L	E308	E308	E308	E308	E308	E308	E308; E312	E308	E308L	E308	E308L	E308L	E312; E309	E308L
								E308; E310	E308	E308	E308	E310; E308	E310; E308	E312	E308	E308	E308	E308	E308	E312; E309	E308
									E308	E308	E308	E308	E308	E308; E312	E308	E308	E308	E308	E308	E312; E309	E308
										E309	E309	E309	E309	E309; E312	E309	E309; E316	E309	E309	E308; E347	E312; E309	E308; E347
											E309S(i); E309	E309	E309S(i); E309	E309; E312	E309S(i); E316L	E316	E316	E316	E308; E347	E312; E309	E308; E347
												E310	E310	E310; E312	E316	E316	E317	E317L(j)	E308	E312; E310	E308; E347
													E310	E310; E312	E316	E316	E317	E317L(j)	E308	E312; E310	E308; E347
														E310; E312	E316	E316	E317	E317	E308	E312; E310	E308
															E316;(k)	E316	E316	E316	E308	E312; E309	E308;(k)
																E316L	E316	E316L	E308L	E312; E309	E316L
																	E317	E317	E308	E312; E309	E308L;(k)
																		E317L(j)	E308L; E347	E312; E309	E308L
																			E347	E312; E309	E347
																				E330	E312; E309
																					E347

When two or more electrodes are listed for a given combination of base metals, the first is suitable for most applications. Others have been listed as alternates or as recommendations for more demanding applications, or for use where cracking might occur with particular lots or heats of material welded with the first electrode. The service requirements of the joint will dictate the most suitable electrode. Recommended electrodes were selected because they are adequate for most applications, and because they are commonly available. The recommendations do not imply that other electrodes would be unsuitable for many applications. In those instances the electrodes shown were selected on the basis of material costs.

Suppliers may be contacted regarding preheat and postheat treatments for best serviceability.

Electrode designations are in accordance with the following AWS-ASTM Filler Metal Specifications: Stainless steels, AWS A5.4, ASTM A298; nickel-base alloys, AWS A5.11, ASTM B295; mild steels, AWS A5.1, ASTM A233; low alloy steels, AWS A5.5, ASTM A316; copper alloys, AWS A5.6, ASTM B225.

(a)Includes selenium-bearing grade, although welding usually is not recommended for any of the free-machining steels when high quality joints are required.

(b)Not a standard AISI grade designation.

(c)Weld metal will be somewhat lower in strength than base metal.

(d)Butter chromium steel with E309, complete joint with E308.

(e)ENiCrFe-3 preferred, especially for joints for high temperature service in low sulfur atmospheres, or when one member is a copper-bearing alloy.

(f)Butter chromium-nickel steel with E312, complete joint with E310.

(g)Butter chromium steel with E309 and chromium-nickel steel with E312, complete joint with E309.

(h)E3[illegible] recommended for cryogenic applications.

(i)E309S is not a standard electrode designation. The "S" implies 0.08% C max compared with a 0.15% C max for E309.

(j)E317L is not a standard electrode designation. The "L" implies 0.04% C max compared with 0.08% C max for E317.

(k)E16-8-2 recommended for less embrittlement during long-time high temperature service.

(l)E309 or E310 may be used when matching composition weld metal is not required.

(m)Special electrode with matching composition (including carbon content) required when hardness of quenched and tempered weld metal must equal that of base metal.

(n)28Cr is not a standard electrode designation. It signifies an electrode which has a typical as-deposited analysis of 0.10 C, 1.0 Mn, 0.50 Si, 29 Cr and 0.15 N.

(o)Butter copper-nickel member with two or more layers of ENiCrFe-3; complete joint with ENiCrFe-3.

(p)Butter free-machining steel with two layers of E309 (E312 for chromium-nickel free-machining steel); complete joint with ENiCrFe-3.

(q)Butter free-machining steel with two layers of E309 (312 for chromium nickel free-machining steel); and butter nickel-copper member with one or two layers of ENiCrFe-3, complete joint with ENiCrFe-3.

(r)Any E60XX or E70XX mild steel electrode.

(s)E8015-B2L, E8016-B2, or E8018-B2 (low alloy steel electrodes).

(t)E9015-B3L, E9015-B3, E9016-B3, or E9018-B3 (low alloy steel electrodes).

(u)E7015, E7016, E7018 or E7028 (mild steel electrodes).

for Welds Between Stainless and Heat Resisting Steels

348	403	405	410	414	416(a)	420	430	430F(a)	431	440A	440B	440C	446	501	502	505(b)
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308, E312	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(l)	(g); E309	(g); E309	(g); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308L	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309	(d); E309	(d); E309
E308; E347	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309; (e)	(d); E309; (e)	(d); E309;(e)
E308; E347	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309; (e)	(d); E309; (e)	(d); E309;(e)
E308; E347	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E309; E310;(e)	E310; (e)	E310;(e)	E310; (e)
E308; E347	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E309; E310;(e)	E310; (e)	E310; (e)	E310; (e)
E308	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E309; E310;(e)	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)
E308; E316	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)
E316L	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309;(e)	(d); E309; (e)	(d); E309; (e)
E308L;(k)	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309; (e)	(d);E309; (e)	(d); E309; (e)
E308L	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309; (e)	(d); E309;(e)	(d); E309; (e)
E347	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	E310;(e)	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)
E312; E309	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312	(g); E312; (e)	(g); E312; (e)	(g); E312; (e)
E347	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d). E309	(d); E309; (e)	(d); E309;(e)	(d); E309; (e)
E348	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d); E309	(d). E309	(d); E309	(d); E309	(d); E309; (e)	(d); E309;(e)	(d); E309; (e)
	E410;(l)	E410;(l)	E410;(l)	E410;(l)	E410;(d)	E410;(l)	E430;(l)	E309	E410;(l)	E410;(l)	E410;(l)	E410;(l)	E410;(l)	E502; (l)	E502; (l)	E505; (l)
		E410;(l)	E410;(l)	E410;(l)	E410;(d)	E410;(l)	E430;(l)	E309	E410;(l)	E410;(l)	E410;(l)	E410;(l)	F410;(l)	E502; (l)	E502; (l)	E505; (l)
			E410;(l)	E410;(l)	E410;(d)	E410;(l)	E430;(l)	E309	E410;(l)	E410;(l)	E410;(l)	E410;(l)	E410;(l)	E502; (l)	E502; (l)	E505; (l)
				(m); E309	E410;(d)	E410;(l)	E430;(l)	E309	E410;(l)	E410;(l)	E410,(l)	E410;(l)	E410;(l)	E502; (l)	E502; (l)	E505; (l)
					E410; E309	E309	E410; E309	E309	E410; E309	E309	E309	E309	E309	E309	E309	E309
						E420; E410;(l)	E410;(l)	E309	E410;(l)	E420;(l)	E420;(l)	E420;(l)	E430;(l)	E502; (l)	E502; (l)	E505; (l)
							E430;(l)	E309	E430;(l)	E430;(l)	E430;(l)	E430;(l)	E430;(l)	E502; (l)	E502; (l)	E505; (l)
								E309	E309	E309	E309	E309	E309; E310	E309	E309	E309
									(m); E309	(m); E309	(m); E309	(m);E309	E309; E310	E502; (l)	E502; (l)	E505; (l)
										(m); E309	(m); E309	(m);E309	E309; E310	E502; (l)	E502; (l)	E505; (l)
											(m); E309	(m);E309	E309; E310	E502; (l)	E502; (l)	E505; (l)
												(m);E309	E309; E310	E502; (l)	E502; (l)	E505; (l)
													28 Cr(n); E310	E502; (l); (e)	E502; (l); (e)	E505; (l); (e)
														(m); E502; (l)	E502; (l)	E502; (l)
															E502; (l)	E502; (l)
																E505; (l)

FACT SHEET.

Covered Electrodes Recommended for Welds Between Stainless, Heat Resisting and Carbon Steels and Other Alloys

Base Metals →	Carbon Steel	1 1/4Cr-1/2Mo	2 1/4Cr-1Mo	Nickel	Inconel	Monel	Copper-Nickel Alloys
201	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
202	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
301	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
302	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
302B	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
303(a)	(g); E309	(g); E309	(g); E309	(p)	(p)	(p)	(q)
304	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
304L	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
305	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
308	(d); E309	(d); E309	(d); E309	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
309	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
309S	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
310	E310; (e)	E310; (e)	E310; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
310S	E310; (e)	E310; (e)	E310; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
314	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
316	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
316L	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
317	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
317L(b)	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
321	(d); E309; (e)	(d); E309; (e)	(d); E309; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
330(b)	(g); E312; (e)	(g); E312; (e)	(g); E312; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
347	(g); E312; (e)	(g); E312; (e)	(g); E312; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
348	(g); E312; (e)	(g); E312; (e)	(g); E312; (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
403	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
405	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
410	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
414	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o); ENiCrFe-3
416(a)	E309	E309	E309	(p)	(p)	(p)	(q)
420	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
430	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
430F(a)	E309	E309	E309	(p)	(p)	(p)	(q)
431	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
440A	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
440B	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
440C	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
446	(r); (l); (e)	(s); (l); (e)	(t); (l); (e)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
501	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
502	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
505	(r); (l)	(s); (l)	(t); (l)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
Carbon Steel	(r)	(u)	(u)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
1 1/4Cr-1/2Mo		(s)	(s)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
2 1/4Cr-1Mo			(t)	ENiCrFe-3	ENiCrFe-3	ENiCrFe-3; ENiCu-2	(o)
Nickel				ENi-1	ENiCrFe-3	ENiCu-2	ECuNi; ENiCu-2
Inconel					ENiCrFe-3	ENiCu-2; ENiCrFe-3	ECuNi; ENiCu-2
Monel						ENiCu-2	ECuNi; ENiCu-2
Copper-Nickel Alloys							ECuNi

AIRCO EASYARC[R] STAINLESS STEEL ELECTRODES

GENERAL DESCRIPTION

Airco Easyarc Stainless Steel Electrodes--an innovation made possible through Airco Engineering whereby a mild steel core wire is utilized. This core wire is covered with a flux coating containing the chromium and nickel measured accurately to meet exacting metallurgical standards. These electrodes, the two principal AISI Type 308 and 316, have been tried and proven in industry. The performance and economies effected are unsurpassed. The practice of adding chemistry to low alloy electrodes through the coating is standard procedure, however, the development of a stainless electrode in this manner is a "First" for Airco. Stainless steel fabricators using these electrodes have found they fully meet their corrosion-resistant and strength requirements.

Low initial cost, together with less change over time and decreased stub loss, make for unusually large money savings. Inches of weld metal per electrode exceed conventional electrode lay down length by roughly 2 to 1. Spatter is extremely low and the slag is easily removed.

WELDING PROCEDURES

Alternating or direct current, reversed polarity may be used with this electrode and it is important that a short arc be maintained at all times if best results are expected.

The deposits of the Easyarc electrode wet and spread readily as applied, so that no manipulation of the electrode is required to produce smooth, uniform deposits of excellent appearance in the flat or horizontal positions.

Single pass fillet welds are accomplished by directing the electrode into the joint at an angle approximately 45° and tilted about 10° in the direction of travel. There should be no lateral manipulation. Stringer beads are also used for multiple pass